AD-A069 114 FOXBORO ANALYTICAL BURLINGTON MA F/G 11/8

WEAR PARTICLE ANALYSIS OF GREASE SAMPLES.(U)

APR 79 E R BOWEN, J P BOWEN N68335-76-C-2281

UNCLASSIFIED NAEC-92-129 NL

1 OF 1

AD A069114

END

DATE FILMED

6-79

DDC

LEVEL II

12

NAVAL AIR ENGINEERING CENTER

REPORT NAEC-92-129

LAKEHURST, N.J.
08733

WEAR PARTICLE ANALYSIS OF GREASE SAMPLES

Handling and Servicing/Armament Division
Ground Support Equipment Department
Naval Air Engineering Center
Lakehurst. New Jersey 08733

18 APRIL 1979

Technical Report
Contract NAVY N68335-76-C-2281

Prepared for

Commander, Naval Air Systems Command
AIR-340E
Washington, D.C. 20361

NAEC-92-129

WEAR PARTICLE ANALYSIS OF GREASE SAMPLES

Prepared by: E Roderic Bowen
J. . Bowen/E. Roderic Bowen
Foxboro Analytical Division
The Foxboro Company

Reviewed by: P. B. Senholzi
P. B. Senholzi
Handling and Servicing/Armament
Division (927)

Approved by: F. E. Evans
F. E. Evans
Ground Support Equipment Superintendent

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE	READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER: (18) NAEC-92-129 (19) 92-129 — 2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle): (6) WEAR PARTICLE ANALYSIS OF GREASE SAMPLES.	5. TYPE OF REPORT & PERIOD COVERED: (9) TECHNICAL rept.
	6. PERFORMING ORG. REPORT NUMBER: NAEC-92-129
7. AUTHOR(s): (10) E. RODERIC BOWEN, JOHN P. BOWEN	8. CONTRACT OR GRANT NUMBER(s): (15) NAVY N68335-76-C-2281
9. PERFORMING ORGANIZATION NAME AND ADDRESS: FOXBORO ANALYTICAL DIVISION, THE FOXBORO COMPANY, BURLINGTON, MA 01803 — 411 159	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS: NAVAL AIR SYSTEMS COMMAND, CODE - AIR 340E, WASHINGTON, DC 20361	12. REPORT DATE: (11) 18 APRIL 1979
	13. NUMBER OF PAGES: 84
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office): GROUND SUPPORT EQUIPMENT DEPARTMENT, CODE 92724, NAVAL AIR ENGINEERING CENTER, LAKEHURST, NEW JERSEY 08733	15. SECURITY CLASS. (of this report): UNCLASSIFIED
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release. Distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

(12) 84 p.

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

FERROGRAPHY
GREASES
GREASE SOLVENTS
GREASE SAMPLING TECHNIQUES
WEAR PARTICLE ANALYSIS
MACHINERY HEALTH MONITORING
FERROGRAPHIC ANALYSIS OF FRESH AND USED GREASES

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

An investigation was conducted to analyze a number of widely used types of grease samples by Ferrography. Solvent systems were successfully formulated to dissolve these greases for analytical purposes. A number of grease samples from aircraft components were subjected to Ferrographic analysis and results reported.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE
S/N 0102-LF-014-6601

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

411 159

SUMMARY

The use of wear particle analysis for monitoring or diagnosing the condition of oil-lubricated bearings is now well established, and because many critical bearings are lubricated with grease, an investigation was authorized to assess the extent to which the use of this technology could be widened to cover grease-lubricated bearings.

During normal operation, only a small proportion of the grease within a bearing plays a significant part in its lubrication. Particles arising from wear are, therefore, very unevenly distributed. Accordingly, it was decided that the sample should be taken from the actual component wear track. This would be dissolved in a suitable fluid from which samples might be selected for use in the same way as with oil-lubricated systems.

A number of solvents were investigated both singly and in combination and a blend consisting of 30% toluol and 70% hexane was shown to be suitable, particularly when mixed with its own volume of diester based lubricant (to MIL-L-23699 specifications).

Ferrography was utilized as the prime wear particle analysis technique. Heating the Ferrogram to 625^{o}F (330^{o}C) for 90 seconds was shown to permit more satisfactory examination and analysis of metallic wear particles because it eliminated an organic residue which was sometimes present.

The use of the aforementioned solution is recommended, but care in handling the solvent is necessary because of the low flash point of hexane.

A number of Ferrograms relating to bearings used in helicopters were obtained with complete success.

TABLE OF CONTENTS

I. INTRODUCTION

A. WEAR PARTICLE ANALYSIS TECHNOLOGY ADAPTATION TO GREASE-LUBRICATED COMPONENTS. Wear particle analysis is now a well developed technology for the study of oil-lubricated systems. Critical wear particle parameters defined under this technology are concentration, size distribution, composition and morphology. The monitoring of these parameters in oil-lubricated systems is for the most part straightforward. Many wear components, however, are lubricated with grease and at the present time there exists no acceptable procedures for monitoring the wear condition of such components.

The nature of the grease lubricant creates several problems with respect to the monitoring of the above mentioned four critical wear particle parameters. The main difficulty is that a simple measurement of the wear metal concentration in a grease sample does not necessarily reflect the wear condition of the lubricated component. There are at least two reasons for this situation. First, the products of wear are not distributed uniformly in the grease. Hence, a grease sample will not necessarily reflect the total wear product concentration. Second, the products of wear do not leave the component and consequently the wear particle concentration will increase with time. Thus the equilibrium concentration, characteristic of oil-lubricated systems, does not exist in grease-lubricated systems.

As a result of the concentration measurement difficulties, grease wear particle analysis will be forced to rely heavily on the remaining three critical parameters of size distribution, composition and morphology.

The objective of this research effort is to develop techniques for the study of wear particles/wear particle parameters in grease-lubricated systems as well as trends with respect to analysis criteria.

Wear particle critical parameters are monitored under this effort by use of the well documented technique of Ferrography. Ferrography will thus receive major emphasis in the following summary report.

B. USE OF GREASES IN AIRCRAFT EQUIPMENT. The decision of the designer as to whether to use oil or grease as a lubricant depends on the operating conditions of the system to be lubricated, particularly the mechanical and thermal aspects. Greased bearings have come into very wide use for mechanisms which are widely separated physically, such as the wheel bearings on automobiles or control surface bearings in aircraft. Modern sealed greased bearings exhibit long life, and in many applications, are economically attractive with respect to both initial and maintenance costs. Many other mechanisms such as splines and hinges are commonly grease-lubricated. Recently, high-powered helicopter gear trains have been successfully lubricated with grease.

C. CHARACTERISTICS OF GREASE FORMULATIONS. Greases are two-phase systems incorporating a liquid and a solid phase. They possess a gel structure with characteristic rheological properties which are determined by the type and concentration of the thickener, the type of lubricating oil, and the amount and properties of materials added to the grease to achieve specific

characteristics. The thickener may be a soap, an organic compound, a complex material made up of organic and inorganic compounds, or a combination of these. Greases are thus very complex and numerous variables affect their physical and chemical characteristics, and in turn their performance in service.

D. CHARACTERISTICS OF GREASE PERFORMANCE. The factors affecting the grease performance in service are many and include temperature, contact with metals, contamination by dirt or moisture, and bearing stresses. These factors can affect either one or more components (oil, thickeners, or additives) of the greases.

Observations on the movement and structure of grease in roller bearings[1] have shown that in a grease-lubricated roller bearing, only the small amount of grease between the rollers and races provide the lubrication. The pockets of grease held by the retainer are relatively inactive. The principal role of the grease in the pockets appeared to be to keep in position the small amount of material responsible for lubrication and to replenish the oil as it is lost by evaporation or degradation. Thus, in a correctly operating grease-lubricated bearing, a small amount of grease becomes severely worked and degraded, whereas the bulk of the grease remains in an almost virgin state.

The movement of wear particles in a grease-lubricated part is restricted to the region where the active grease is located. Therefore, a basic problem in monitoring grease-lubricated parts is that the simple measurement of the concentration of an element in the bulk grease provides no information regarding the wear rate. This occurs because the concentration of wear particles is not uniform throughout the grease and varies with the place from which the grease was sampled.

E. SELECTION OF GREASE SOLVENT SYSTEMS. In order to apply the techniques of Ferrography to grease-lubricated bearings, two aspects have to be considered. First it is necessary to discover a solvent which will dissolve the grease sample so as to produce a fluid of suitable viscosity for Ferrographic examination. Second, it must be demonstrated that the particles found in the grease are accurately represented in the fluid sample.

Because the ingredients used in grease formulations are diverse, the selection of a single solvent for all greases appears to be a difficult task. Solid additives incorporated in greases are insoluble. A wide variety of soaps or thickeners may be used by different manufacturers with the same liquid lubricant to comply with specific grease requirements and the same specifications. Further differences in greases from manufacturer to manufacturer may result from differences in manufacturing procedures. For example, one manufacturer may use a soap base to thicken a specific lubricating fluid, while another may incorporate the soap-making procedure in the grease manufacturing process.

[1] A. A. Milne, D. Scott, and H. M. Scott "Observations on the Movement and Structure of Grease in Roller Bearings", Proc. Conf. on Lubrication and Wear, 1957. 450-453 and 893. Inst. Mech. Engrs., London, 1958.

The concentration, distribution and size of the solid phases may also vary in unused greases.

F. <u>DEVELOPMENT OF RELIABLE GREASE SAMPLING/ANALYSIS TECHNIQUES</u>. It was therefore necessary to establish a reliable technique for sampling grease and to select solvents which could be used to dissolve greases of all types. It was also necessary to demonstrate that once a sample of grease had been treated with a suitable solvent, that the same wear particle monitoring trends could be used as have been successfully applied to the analysis of oil samples.

II. SELECTION OF SOLVENTS BASED ON UNUSED GREASES

A. GREASE FORMULATIONS SELECTED FOR STUDY. In order to conduct solvating studies covering a range of combinations of ingredients in the more commonly employed greases, samples were obtained of the nine greases listed in Table 1. Their basic ingredients and specific uses are given. The nine greases cover a range of fluid lubricants, soap phases, and solid additives.

B. GREASE SOLVENT SYSTEMS SELECTED FOR STUDY. Three solvent systems were initially chosen for solvation studies on the nine unused greases. As the solvency power of a solvent system on different materials cannot be accurately predicted, the three solvent systems chosen had varying balances of polar, nonpolar, and aromatic or aliphatic constituents. The solvents are listed in Table 2.

The initial solvation studies were conducted with the first four greases listed in Table 1. These were reported to be the greases most used in service.

C. SOLVATING TEST METHODS. The solvating test method chosen was to introduce ten 3-mm-diameter glass beads into a standard Ferrographic sample bottle, the capacity of which is 1/2 U.S. fluid ounce (15 ml). A small amount, approximately .1 cc, of grease and 10 ml of the solvent to be tested were added. The bottle was then sealed and well shaken by hand. Previous experience had indicated that the use of glass beads considerably shortened the time of agitation required for grease solution and exhibits no negative effects on particle analysis.

A Ferrograph was prepared from 2 ml of the contents of the bottle immediately after shaking. Following the pumping of the grease solvent mixture, the Ferrogram was washed by pumping the pure solvent over the Ferrogram. The Ferrogram was washed by passing the test solvent over it for 10 minutes.

Summarized test results on the unused greases and different solvent systems are given in Table 3.

D. INITIAL RESULTS OF SOLVATING TESTS WITH DIFFERENT UNUSED GREASE FORMULATIONS. Solvent #1 was found to be ineffective in lithium soap greases. For record purposes, photomicrographs of undissolved grease deposits on Ferrograms of lithium soap greases are shown in Photos Nos. F1428-1 to -6 (appendix B, pages 29(B-1) to 31(B-3)). Heating of the Ferrogram to 625°F was ineffective in removing the undissolved lithium soap, Photo No. F1423-32 (appendix B, page 45(B-17)).

Solvent #2, incorporating three liquids (toluol/MEK/isopropanol) was considered to be a potentially more powerful solvating medium than Solvent #1, as mixtures of solvents generally produce synergistic effects. It is often found that a material insoluble in either of two solvents is soluble in a mixture of the solvents. However, Solvent #2 was found to be a less effective solvent for lithium soap greases than Solvent #1. It is evident that lithium soap greases resist solvation in highly polar/aromatic solvent systems.

Solvent #3, containing less aromatic solvent (30% toluol) and more non-polar aliphatic solvent (70% hexane), proved to be effective for the solution of lithium soap/petroleum oil type grease as shown in Photos Nos. F1437-7 and -8 (appendix B, page 32(B-4)). This solvent was therefore used to treat the remaining grease samples.

E. <u>FERROGRAPHIC ANALYSIS OF DIFFERENT TYPES OF GREASE SAMPLES</u>. Ferrograms of certain grease samples, but especially those from Sample #4, a lithium soap silicone grease, contained particulate matter as shown in Photos Nos. F1442-13 to -18 (appendix B, pages 35(B-7) to 37(B-9)). Consultation with the grease manufacturer revealed that the lithium soap silicone grease contained approximately three times the amount of lithium soap (up to 35%) than that contained by a petroleum oil lithium soap grease. It was also suggested that the white lumps seen on the Ferrograms, Photos Nos. F1442-15 and -16 (appendix B, page 36(B-8)), were particles of the original soap rather than additive material. It was postulated that service use of this grease caused the soap particles to flatten out. Such modified particles were observed on Ferrograms prepared from worked grease as shown in Photos Nos. F1491-36 to -39 (appendix B, pages 47(B-19) and 48(B-20)).

Particulate matter was also found on Ferrograms prepared for grease Samples #6 and #7 containing molybdenum disulphide and for grease Sample #8, a barium soap grease. The Ferrogram prepared from the latter type of grease contained an organic-type network which was eliminated by heating the Ferrogram to 625°F for 90 seconds as shown in Photos Nos. F1443-26 to -31 (appendix B, pages 42(B-14) to 44(B-16)). Diluting the grease volumetrically 10:1 with Solvent #3 dispersed the weblike organic material as shown in Photos Nos. F1479-33 and -34 (appendix B, pages 45(B-17) and 46(B-18)). A volumetric dilution is preferable since an increased error due to particulate density effects in heavily contaminated samples is minimized.

The presence of molybdenum disulphide in the grease (Samples #6 and #7) caused problems. The large particles of molybdenum disulphide settled on the bottom of the sample bottle and did not transfer to the Ferrogram. This problem was overcome by mixing the solvent-treated sample with equal parts of a diester fluid (MIL-L-26399) as can be seen from Photos Nos. F1440-21, -22 and -23 (appendix B, pages 39(B-11) and 40(B-12)).

A second problem was that the large particles of molybdenum disulphide could obscure wear particles precipitated from the grease onto the Ferrogram. The morphology of the molybdenum disulphide particles was significantly changed by test working of the grease. The change of morphology is discussed under solvation studies of used greases.

Grease #7, with a lower concentration of molybdenum disulphide, caused no problem. Photos Nos. F1478-9 and -10 (appendix B, page 33(B-5)) show typical Ferrograms prepared from this grease.

Greases #3, #5, #7 and #9 were effectively dissolved by Solvent #3. Photos Nos. F1439-11 and -12 (appendix B, page 34(B-6)) show typical Ferrograms prepared from grease #3 which contained a diester fluid with a silicone

thickener. Photos Nos. F1434-19 and F1438-20 (appendix B, page 38(B-10)) show comparative Ferrograms prepared from grease #5 containing petroleum oil with an aluminum complex soap with Solvent #2 and #3 respectively. Photos Nos. F1441-24 and -25 (appendix B, page 41(B-13)) show typical Ferrograms prepared from grease #7 containing petroleum oil thickened with a Bentone clay and molybdenum disulphide. Photo No. F1474-35 (appendix B, page 46(B-18)) shows a typical Ferrogram prepared from grease #9 which contained petroleum oil and a calcium soap and which is completely clear except for "dirt" particles.

III. WORKED GREASES

A. TEST MACHINE CONDITIONS. The three unused greases found most difficult to dissolve for Ferrographic analysis procedures #4, #6 and #8 were subjected to working in a test machine before being used for further solvation studies. The grease working test consisted of rubbing an AISI 52100 steel race against a fixed steel bearing ball under a load of 80 lb/in.^{2} for 2 minutes. A small quantity of unused grease was used for each test. Small samples of each worked grease were treated with Solvent #3 according to the procedure described for the unused grease samples (paragraph II.C). Ferrograms were prepared from each sample. Table #4 summarizes the data produced in these tests.

B. FERROGRAPHIC ANALYSIS OF CERTAIN TYPES OF WORKED GREASES. As already shown in Photos Nos. F1491-36 to -39 (appendix B, pages 47(B-19) and 48(B-20)), working of the lithium soap silicone grease #4 reduced the size of the undissolved particulate matter deposited on the Ferrogram, and also eliminated its interference with the interpretation of the Ferrogram. Even in the presence of a background of undissolved grease, wear particles precipitated from the grease can be satisfactorily analyzed by bichromatic microscopy.

For satisfactory Ferrogram preparations from grease sample #6, containing a large particle size molybdenum disulphide additive, it was necessary to dilute the sample by the addition of a diester fluid, MIL-L-23699. Photos Nos. F1493-40 and -41 (appendix B, page 49(B-21)) show the few particles on Ferrograms prepared from the unworked grease without dilution with the diester fluid. Photos Nos. F1494-42 and -43 (appendix B, page 50(B-22)) show metallic wear particles precipitated on the Ferrogram prepared from the worked grease sample diluted with diester fluid.

C. SPECIAL TECHNIQUES IN ELIMINATING ORGANIC BACKGROUND MATERIAL ON FERROGRAMS. The background network of organic material found on Ferrograms prepared from unused barium soap base petroleum oil grease #8 was also found on Ferrograms prepared from worked samples of the same grease, but to a lesser extent. Particles forming the network were also reduced in size, see Photos Nos. F1492-44 and -45 (appendix B, page 51(B-23)). Heating of the Ferrogram to 625°F (330°C) for 90 seconds eliminated the organic material to allow more satisfactory examination and analysis of the metallic wear particles (see Photo No. F1492-46, appendix B, page 52(B-24)).

IV. EXAMINATION OF SAMPLES TAKEN FROM GREASE LUBRICATED SYSTEMS OF AIRCRAFT, NAVAL AIR REWORK FACILITY (NARF), SAN DIEGO, CALIFORNIA

A. TYPES OF AIRCRAFT AND SAMPLES. A number of samples were taken from critical areas of fixed-wing aircraft and helicopters at the Naval Aircraft Rework Facility (NARF), San Diego, California, and subjected to Ferrographic analysis at Foxboro Analytical. Particulars of these samples are summarized in Table 5 and photographs of the Ferrograms are also reproduced.

This report does not purport to include a definitive account of the conclusions to be drawn from the examination of the respective aircraft components, but the observations are reported as evidence of the potentiality of grease wear particle analysis techniques.

B. FERROGRAPHIC ANALYSIS OF AIRCRAFT GREASE SAMPLES (TABLE 5). The field sample Ferrogram photograph, No. F1940-1 (appendix B, page 53(B-25)), (E2 landing gear nosewheel sample) reveals translucent material which is accounted for by soap remaining from degradation of the grease, but appears to be exceptional insofar as the majority of the Ferrograms do not exhibit this feature. Where it does occur, it is readily identifiable and is easily distinguished from wear particles. This example also emphasizes the care necessary in sampling because of the risk of contamination of the grease from external sources. The metallic particles in Photo No. F1940-1 probably originate in this manner. On the other hand, those in Photo No. F1943-1 (appendix B, page 53(B-25)) are probably wear particles because they occur in grease removed directly from the race.

A similar sample from the race of a tapered roller bearing, of a landing gear nosewheel, showed free metal particles and was free of residual grease (see Photo F1964-1, appendix B, page 54(B-26)).

A number of samples which were taken from the swash plate assembly of an H53 helicopter again serves to emphasize the critical nature of the sampling process. A sample taken from behind the spaces between the two rolling bearings, revealed a surprising number of severe wear particles (see Photo No. F1946-1, appendix B, page 55(B-27)) whereas a sample taken from around the ball of the upper bearing showed heavy deposits of friction polymer (see Photo No. F1966-1, appendix B, page 55(B-27)). However, a sample taken from the grease exuded from under the assembly seals (Photo No. F1965-1, appendix B, page 54(B-26)), contained mostly contaminants and non-wear related debris.

Samples from a helicopter reduction gear showed a certain amount of cutting wear in a sample taken from the planetary gear teeth (Photo No. F1987-1, appendix B, page 62(B-34)).

The stationary splines at the rotor head of the H46 helicopter were investigated (Photos Nos. F1960-1, F1961-1 and F1962-1, appendix B, pages 63(B-35) and 64(B-36)). Grease taken from the spline showed severe wear particles. The similarity of Ferrograms (Photos Nos. F1961-1 and F1962-1) suggest that the particle distribution does not vary alarmingly along the wear track of an individual component.

Samples from the tail rotor drive spline of the CH 53A aircraft (Photos Nos. F1990-1 and F1991-1, appendix B, page 65(B-37)) revealed no evidence of serious wear, but the sample was very dirty, presumably due to the fact that the components are open to environment when the craft is in the parked position. (When running, the components are protected by O-ring seals.)

V. DISCUSSION

A. FEASIBILITY OF FERROGRAPHIC ANALYSIS OF GREASE SAMPLES. The results reported in Section III demonstrate the feasibility of obtaining satisfactory Ferrograms from grease-lubricated components. The examination of such components (primarily bearings) is not, however, as straightforward as when oil is used as a lubricant for two reasons. First, the distribution of wear particles within the grease is very uneven; and second, because the physical configuration of most components precludes the extraction of grease without actual dismantling.

B. SELECTION OF GREASE SAMPLES. There will be many situations where "condition monitoring" using Ferrography will be precluded by sampling difficulties. However, in systems where sampling can be carried out readily, similar techniques to those perfected for oil-lubricated systems can be applied. In many cases, however, it will not be feasible to dismantle components for sampling, and the role of Ferrography will be restricted to failure analysis of those components which have been dismantled for one reason or another.

VI. CONCLUSIONS

A. Grease Solvent #3 (toluol/hexane) was the most effective for use with the wide range of grease samples investigated. It appears to be potentially suitable as a general solvent for all greases. It should contain up to 50% of diester (MIL-L-23699) to suspend high-density large particle material and to prevent co-settling of wear particles (Paragraph IID).

B. Commonly used solid additive materials such as molybdenum disulphide and carbon black (graphite) present no difficulty to Ferrographic analysis if the dissolved sample diluting procedure developed is used (Paragraph IIF).

C. Many insoluble organic materials present in greases, if deposited on Ferrograms, may be eliminated by heating the Ferrogram after initial analysis (Paragraph IIIC).

D. The use of glass beads to speed up the grease solvating process should be incorporated in any standard grease Ferrogram preparation procedure (Par. IIC).

E. The use of hexane, which has a low flash point, may not be desirable. Further work on solvents could be directed towards replacing hexane with a higher flash point aliphatic material of comparable solvency power (Paragraph IID).

F. The wash for the Ferrograms may be similar to the grease solvent. Incorporation of a material to effect quick drying may be required if a solvent of higher flash point than hexane is utilized (Paragraph IIC).

G. Ferrograms can be made from grease-lubricated bearings of a quality which is comparable with that achievable with oil-based samples (Paragraph VA).

H. Sampling of grease from bearings may be difficult due to lack of access. It is also important to take into account the uneven dispersion of wear particles within the bearing system. This limits quantitative analysis techniques (Paragraph VA).

I. Samples should be taken directly from the wear track or wear surface (or as close as possible), (Paragraph IVB).

J. The analysis should be primarily qualitative. Quantitative analysis should be performed only on a comparative basis. That is, a comparison of abnormal particles to normal particles within an individual sample. Morphology of the abnormal particles plays a primary role in all grease sample analyses (Par. IVB).

K. Due to the high level of contaminants in fresh grease, it is essential that a Ferrogram of the fresh grease be used as a reference (Paragraph IIE).

L. In the light of the aforementioned difficulties, Ferrography is more likely to be applicable to diagnosis of failure and as a design tool than to condition monitoring. Applications exist, however, where access to the operative regions of a bearing is readily available and where monitoring programs are both feasible and desirable.

M. The types of wear particles present in grease samples are consistent with those found in oil-lubricated systems (Paragraph IVB).

VII. RECOMMENDATIONS

A. It is recommended that the preceding procedures be used as a basis for standardizing the use of Ferrography for the examination of grease-lubricated components.

B. Grease, when extracted from a bearing, should be dissolved in a solvent mixture consisting of 15% toluol, 35% hexane, and 50% diester-based lubricant.

C. Ferrograms may be heated to 330°C (625°F) for 90 seconds to eliminate organic residue from the grease after initial analysis.

D. Care should be taken when storing and handling the recommended solvent because of the low flash point of hexane.

E. Further work should be pursued in the areas of sampling technique, sampling location, and wear particle analysis criteria.

TABLE 1. GREASE TYPES

SAMPLE NO.	BASE OIL	THICKENER (SOAP)	SOLIDS (ADDITIVES)	USES/COMMENTS
1	Petroleum	Lithium Soap	-----	Reported to have the widest general purpose uses. Operating range -10 to 250°F for plain and anti-friction bearings. Molybdenum Disulphide is to improve anti-wear properties and load-bearing characteristics.
2	Petroleum	Lithium Soap	Molybdenum Disulfide	
3	Synthetic Diester	Silica	Silica	Bearings - both low and high temperature use - temperature range -40°F to 500°F.
4	Silicone	Lithium Soap	-----	High temperature bearings, bearings in hot areas - temperature range -40°F to +450°F. Meets MIL Specification MIL-L-15719A, Amendment 3.
5	Petroleum	Aluminum Complex Soap	-----	Extreme pressure bearings and gear-type couplings, also multipurpose. Good water and oxidation resistance. Operating range 0°F to 400°F, intermittent up to 450°F.
6	Petroleum	Mixed (Proprietary)	Molybdenum Disulfide	Heavy duty use, Molybdenum Disulfide to improve load-bearing characteristics. Primary uses (#6) open gears, (#7) couplings. Has "no-drip" characteristics, range 25°F to 400°F.
7	Petroleum	Clay (Bentone)	Molybdenum Disulfide	

(continued ...

Table 1 (continued)

SAMPLE NO.	BASE OIL	THICKENER (SOAP)	SOLIDS (ADDITIVES)	USES/COMMENTS
8	Petroleum	Barium Complex Soap	-----	Multipurpose lubricant, high water resistance. Used for marine, construction, mining. Temperature range 0°F to 250°F.
9	Petroleum	Calcium Soap	-----	Extreme pressure lubricant for gears in bath, semi-fluid type. Temperature range 0°F to 150°F.

TABLE 2. GREASE SOLVENT SYSTEMS SELECTED FOR STUDY

1. GREASE SOLVENT #1

   toluol (50%), isopropanol (50%)

   an aromatic/polar blend

2. GREASE SOLVENT #2

   toluol (33%), methyl ethyl ketone (MEK) (33%), isopropanol (34%)

   an aromatic higher polar blend

3. GREASE SOLVENT #3

   toluol (30%), hexane (70%)

   an aromatic, aliphatic, essentially nonpolar blend

TABLE 3. SUMMARY - SOLVATION STUDIES - VARIOUS GREASE TYPES (FRESH)

SAMPLE NO.	SOLVENT/WASH	FERROGRAM NUMBER	PHOTO NUMBER	RESULTS	COMMENTS/SIGNIFICANCE
No. 1 Lithium Soap	Solvent #1	F1428	F1428 -1 to -6	Solvent #1 (Toluol/ Isopropanol). Not effective with Lithium soap greases.	Highly polar, aromatic solvent systems are inadequate. (Also, see Photo F1423-32).
No. 1 Lithium Soap	Solvent #3	F1437	F1437 -7 & -8	Solvent #3 (Toluol/ Hexane). Appears to be effective in dissolving grease and Lithium Soap. Only insoluble particulate matter visible.	A solvent system with a high aliphatic content is required for complete removal of greases and soap on substrates.
No. 2 Lithium Soap plus Moderate MoS_2 Content	Solvent #3	F1478	F1478 -9 & -10	Grease and soap dissolved. MoS_2 particles were precipitated. Some non-metallic transparent spheres were observed on the Ferrogram.	The low level of the MoS_2 content on the Ferrogram would not obscure metallic particles in used grease. Heavy duty greases with high MoS_2 content may present a problem.
No. 3 **Diester** Base Oil with Silica	Solvent #3	F1439	F1439 -11 & -12	Substrates show no grease or oils, minor amounts of Silica.	This **diester base oil sample** solvates very well in Solvent #3. No special problems observed.
No. 4 Silicone Base Oil with Lithium Soap	Solvent #3	F1422	F1442 -13 to -18	Large amount of insoluble grease, soap, and particulate matter. Some particles up to 200 μm.	High soap content (up to 35%) plus particulate matter may make Ferrographic analysis difficult. Refer to used Silicone grease tests.

(continued ...

Table 3 (continued)

SAMPLE NO.	SOLVENT/WASH	FERROGRAM NUMBER	PHOTO NUMBER	RESULTS	COMMENTS/SIGNIFICANCE
No. 5 Aluminum Complex Soap	Solvent #2	F1434	F1434 -19	Some grease or soap residue evident at entry.	This Solvent, #2, not efficient in solvating action. Compare to F1438 below with Solvent #3 system.
No. 5 Aluminum Complex Soap	Solvent #3	F1438	F1438 -20	Substrate free of grease or soap. Only minor particulate matter evident.	Grease Solvent #3 effective with this type of grease.
No. 6 MoS_2 Solids	Solvent #3	F1440	F1440 -21	Very little MoS_2 deposited on substrate having settled in dissolved sample and turret tube.	Fresh greases with large particles (50 µm range) will not necessarily show the particles on substrate. Compare to F1444 below.
No. 6 MoS_2 Solids	Solvent #3/ MIL-L-23699 (50-50)	F1444	F1444 -22 & -23	Large (50 µm) particle size MoS_2 suspended by oil/solvent mixture.	The amount and size of MoS_2 particles will interfere with Ferrogram analysis. A solvent mixture required suspended MoS_2 particles.
No. 7 MoS_2 Solids plus Clay	Solvent #3	F1441	F1441 -24 & -25	The medium size (5-20 µm) MoS_2 particles deposit in large quantities on substrate. Clay (Bentone) also deposited.	MoS_2 particles obscure entry deposit area.
No. 8 Barium Complex Soaps	Solvent #3	F1443	F1443 -26 to -31	Large network of non-metallic material very heavy at entry and distributed throughout substrate.	Organic material will obscure metallic deposits. Heat to 625°F (F1443-29, -31) clarifies or evaporates the material.

(continued ...

Table 3 (continued)

SAMPLE NO.	SOLVENT/WASH	FERROGRAM NUMBER	PHOTO NUMBER	RESULTS	COMMENTS/SIGNIFICANCE
No. 1 Lithium Soap	Solvent #1	F1423	F1423 -32	Heating Ferrogram to 625°F for 90 seconds does not remove undissolved grease.	Refer to Photos F1428-1 thru -6.
No. 8 Barium Complex Soap	Solvent #3	F1479	F1479 -33 & -34	Dilution (10:1 ratio) reduces agglomerated non-metallic mass to isolated strings, but has tendency to catch on metallic particles (Photo F1479-34).	Dilution appears to free substrate from this organic matter, but effect on used greases would have to be checked.
No. 9 Calcium Soap	Solvent #3	F1474	F1474 -35	Substrate free of soap or grease.	Solvent #3 appears satisfactory for this type of grease.

TABLE 4. SUMMARY - SOLVATION STUDIES - VARIOUS GREASE TYPES (WORKED)

SAMPLE NO.	SOLVENT	FERROGRAM NUMBER	PHOTO NUMBER	RESULTS	COMMENTS/SIGNIFICANCE
No. 4 Silicone Grease	Solvent #3	F1491	F1491 -36 to -39	Photos F1491-36 to -39 show deposits in fresh grease are minimized. Bichromatic illumination may be employed to identify metallic wear particles	Use of Bichromatic light or microscope analysis of Ferrograms of used Silicone grease samples should be confirmed as standard technique.
No. 6 Molybdenum Disulfide	Solvent #3	F1493	F1493 -40 & -41	Photos F1493-40 and -41 have no metallic wear particles, few MoS_2 particles.	50 µm or larger MoS_2 particles settled too fast for Ferrograph pumping.
No. 6 Molybdenum Disulfide	Solvent #3/ MIL-L-23699 Oil 50/50	F1494	F1494 -42 & -43	Photos F1494-42 and -43 have metallic wear particles deposited on substrate.	Oil/solvent mixtures required to both solvate grease and suspend wear particles with some MoS_2 type greases.
No. 8 Barium Complex Soap	Solvent #3	F1492	F1492 -44 to -46	Wear particles identifiable in network of organic material. Heating Ferrogram 330°C (625°F) evaporates organic material.	Bichromatic illumination effective in identifying morphology of metal wear particles.

TABLE 5. EXAMINATION OF SAMPLES TAKEN FROM GREASE-LUBRICATED SYSTEMS

NO.	SOURCE	COMPONENT	NATURE OF SAMPLE	FERROGRAM NUMBER	REMARKS
1	E2 Grumman Aircraft	landing gear nosewheel tapered roller bearing	residual grease	F1940	metallic particles probably initial contamination - residual soap appears as translucent material
2	E2 Grumman Aircraft	landing gear nosewheel tapered roller bearing	grease removed from race	F1943	low wear metal concentration - oxides and compounds may be wear associated but bearing appears normal
3	F4 Landing Wheel	tapered roller bearing outer race	grease from race surface	F1964	Ferrogram free of residual grease - few metallic particles (> 10 μm)
4	H53 Helicopter	swash plate 353 hours since cverhaul	outside of seal - probably residue of fill	F1965	heavily contaminated with particles of carbonaceous appearance indicative of grease deterioration
5	H53 Helicopter	swash plate 353 hours since overhaul	from behind spacer	F1946	many severe wear particles - 100 - 150 μm long
6	H53 Helicopter	swash plate 353 hours since overhaul	upper bearing around ball	F1966	heavy deposit of friction polymer
7	H53 Helicopter	swash plate 353 hours since overhaul	upper bearing around ball, but opposite side	F1967	debris is primarily friction polymer
8	H53 Helicopter	swash plate 353 hours since overhaul	from bearing edge	F1968	rubbing wear some particles show blue

(continued ...

Table 5 (continued)

NO.	SOURCE	COMPONENT	NATURE OF SAMPLE	FERROGRAM NUMBER	REMARKS
9	H53 Helicopter	swash plate 353 hours since overhaul	from bearing edge but without edge grease	F1969	very few normal rubbing particles are present - Ferrogram dominated by non-metallic crystalline debris which is rose colored in polarized light
10	H53 Helicopter	swash plate 353 hours since overhaul	lower bearing inside edge	F1970	normal rubbing wear and friction polymers present - also, some non-metallic crystalline debris as seen on F1969, but in much lower quantity.
11	H53 Helicopter	swash plate 353 hours since overhaul	between two ball bearings (lower)	F1975	brown non-metallic crystalline debris as in F1969 and F1970 after subjection to heat and pressure - normal rubbing wear particles, red oxide particles, and copious friction polymers present
12	H53 Helicopter	swash plate 353 hours since overhaul	between two ball bearings (lower)	F1977	same as Ferrogram F1975, but deposit is lighter
13	Helicopter	reduction gear	from crack in gearbox housing	F1978	light deposit, normal rubbing wear with just a few severe wear particles and little else
14	Helicopter	reduction gear	from minor gear teeth	F1979	negligible wear, same as F1978, but fewer and smaller particles
15	Helicopter	reduction gear	same as 13 but not at crack	F1980	negligible wear, same as F1978, but fewer and smaller particles

(continued ...

Table 5 (continued)

NO.	SOURCE	COMPONENT	NATURE OF SAMPLE	FERROGRAM NUMBER	REMARKS
16	Helicopter	reduction gear	from gear support bearing (Journal)	F1957	severe and cutting wear particles, normal rubbing wear, and friction polymers - heavy deposit on Ferrogram - not similar to F1978, F1979 or F1980
17	Helicopter	reduction gear	planetary gear teeth	F1958	cutting wear and severe wear particles - large particles of friction polymer - normal rubbing wear particles - non-ferrous metal particles (cutting and severe wear) deposited along length of Ferrogram
17	Helicopter	reduction gear	planetary gear teeth 10:1 dilution of above	F1986	
18	H46 Helicopter	reduction gear	from gear support regions	F1959	heavy deposits of friction polymer and severe wear particles many and large cutting wear particles
18	H46 Helicopter	reduction gear	from gear support regions	F1987 10:1 dilution of above	
19	H46 Helicopter	stationary splines at rotor head	from below bottom spline	F1960	low aspect ratio, rather thick, severe wear particles - non-ferromagnetic - dark, metallo-oxide particles, red oxides, friction polymers, and normal rubbing wear

(continued ...

Table 5 (continued)

NO.	SOURCE	COMPONENT	NATURE OF SAMPLE	FERROGRAM NUMBER	REMARKS
20	H46 Helicopter	stationary splines at rotor head	off spline surfaces	F1961	severe wear particles, dark metallo-oxides, red oxides, normal rubbing wear, fatigue chunks (many of which are non-ferromagnetic and non-metallic crystalline debris - rather heavy deposit)
21	H46 Helicopter	stationary splines at rotor head	off spline surfaces	F1962	same as Ferrogram F1961, but deposit is not as heavy
22	CH 53A Aircraft	tail rotor spline	directly from spline	F1990	very heavily particle laden friction polymers, dark metallo-oxides, with very little else
23	CH 53A Aircraft	tail rotor spline	directly from spline	F1991	very heavily particle laden friction polymers, dark metallo-oxides, with very little else

THIS PAGE LEFT BLANK
INTENTIONALLY.

Photo No. F1428-1 Magnification: 100X

Location on Ferrogram: Entry (edge)

Grease Sample: #1

Lubricant Base: Petroleum

Thickener: Lithium Soap

Solids: None

Solvent Type: Solvent #1

Operating History: Fresh grease

Sample Source: Manufacturer

Remarks:

Dissolved in 10 cc grease Solvent #1. Typical example of undissolved grease/soap mixture.

Photo No. F1428-2 Magnification: 100X

Location on Ferrogram: Entry

Grease Sample: #1

Lubricant Base: Petroleum

Thickener: Lithium

Solids: None

Solvent Type: Solvent #1

Operating History: Fresh grease

Sample Source: Manufacturer

Remarks:

Another view of the undissolved grease/soap mixture using Solvent #1.

Photo No. F1428-3 Magnification: 100X

Location on Ferrogram: @ 41 mm

Grease Sample: #1

Lubricant Base: Petroleum

Thickener: Lithium

Solids: None

Solvent Type: Solvent #1

Operating History: Fresh grease

Sample Source: Manufacturer

Remarks:

Large mass of organic material thought to be lithium soap. Highly polar solvent systems are ineffective in dissolving this material.

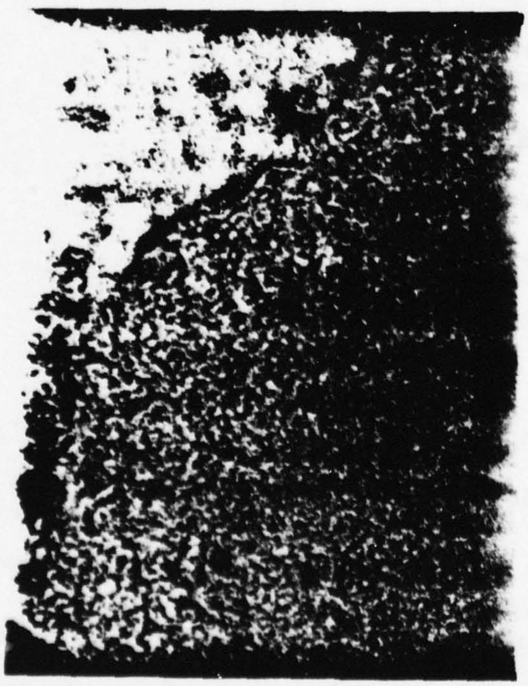

Photo No. F1428-4 Magnification: 100X

Location on Ferrogram: @ 41 mm

Grease Sample: #1

Lubricant Base: Petroleum

Thickener: Lithium

Solids: None

Solvent Type: Solvent #1

Operating History: Fresh grease

Sample Source: Manufacturer

Remarks:

Bichromatic light photo of same material in Photo F1428-3 above. Shows chiefly amorphous nature of undissolved grease.

Photo No. F1428-5 Magnification: 100X

Location on Ferrogram: Entry area

Grease Sample: #1

Lubricant Base: Petroleum

Thickener: Lithium

Solids: None

Solvent Type: Solvent #1

Operating History: Fresh grease

Sample Source: Manufacturer

Remarks:

Polarized light photo shows chiefly amorphous nature of undissolved grease. Some minor particulate matter present.

Photo No. F1428-6 Magnification: 100X

Location on Ferrogram: @ 35 mm

Grease Sample: #1

Lubricant Base: Petroleum

Thickener: Lithium

Solids: None

Solvent Type: Solvent #1

Operating History: Fresh grease

Sample Source: Manufacturer

Remarks:

Another view down the Ferrogram of material thought to be lithium soap apparently swollen by Solvent #1.

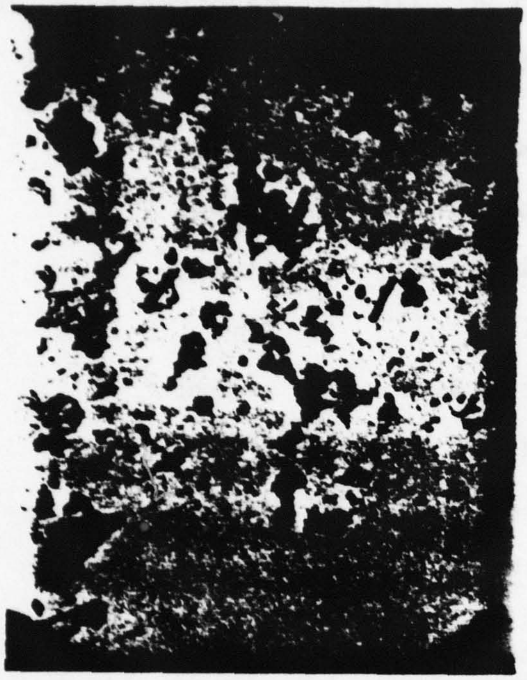

Photo No. F1437-7 Magnification: 100X

Location on Ferrogram: Entry area

Grease Sample: #1

Lubricant Base: Petroleum

Thickener: Lithium

Solids: None

Solvent Type: Solvent #3

Operating History: Fresh grease

Sample Source: Manufacturer

Remarks:

Sample dissolved in grease Solvent #3, (high aliphatic content). Good solvation. No grease or soap evident. Some thin non-metallic particulate matter present.

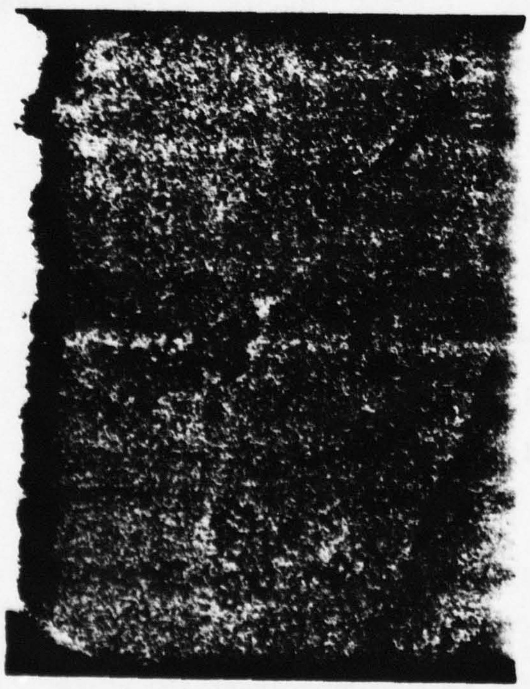

Photo No. F1437-8 Magnification: 100X

Location on Ferrogram: Entry area

Grease Sample: #1

Lubricant Base: Petroleum

Thickener: Lithium

Solids: None

Solvent Type: Solvent #3

Operating History: Fresh grease

Sample Source: Manufacturer

Remarks:

Another view of same Ferrogram. Emphasizes good solvency power of Solvent #3 vs. Solvent #1 (Photos -1 to -6).

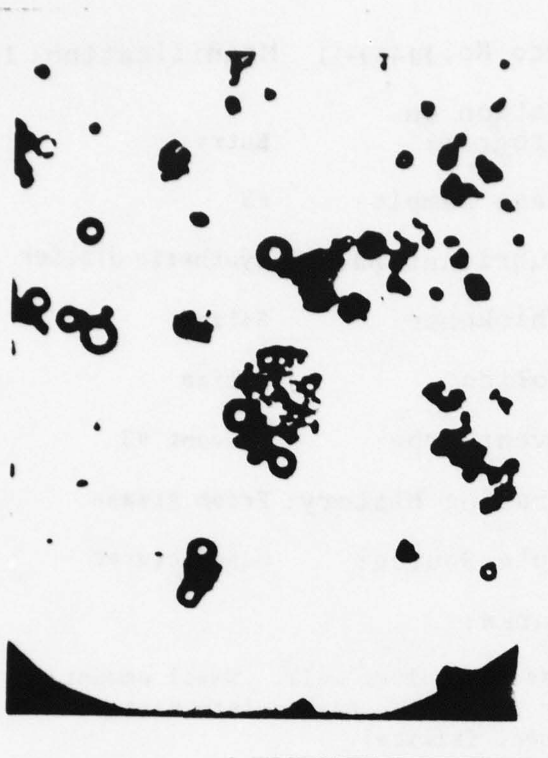

Photo No. F1478-9 Magnification: 100X

Location on Ferrogram: Entry area

Grease Sample: #2

Lubricant Base: Petroleum

Thickener: Lithium

Solids: Molybdneum disulfide

Solvent Type: Solvent #3

Operating History: Fresh grease

Sample Source: Manufacturer

Remarks:

All grease and soap solubilized. Blue/black particles are MoS_2, non-metallic spheres are unknown material.

Photo No. F1478-10 Magnification: 100X

Location on Ferrogram: Entry area

Grease Sample: #2

Lubricant Base: Petroleum

Thickener: Lithium

Solids: Molybdenum disulfide

Solvent Type: Solvent #3

Operating History: Fresh grease

Sample Source: Manufacturer

Remarks:

Bichromatic light photo of same view as in Photo No. F1478-9 above demonstrates transparent spheres are non-metallic.

Photo No. F1439-11 Magnification: 100X

Location on Ferrogram: Entry

Grease Sample: #3

Lubricant Base: Synthetic diester

Thickener: Silica

Solids: Silica

Solvent Type: Solvent #3

Operating History: Fresh grease

Sample Source: Manufacturer

Remarks:

Grease dissolved well. Small amount of non-metallic particulate matter present (silica).

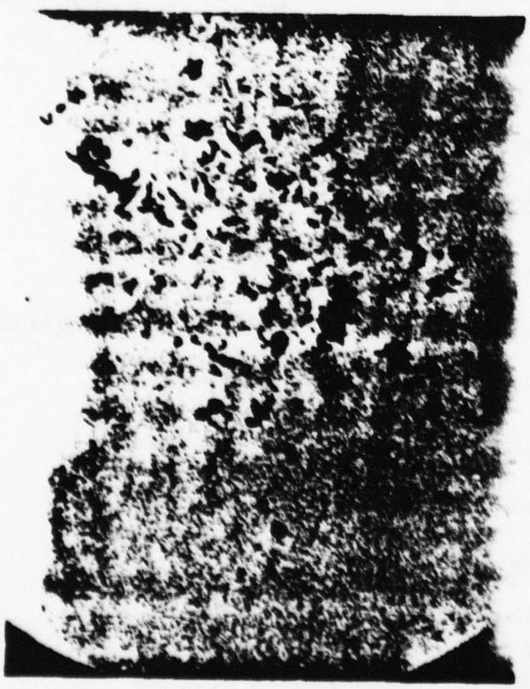

Photo No. F1439-12 Magnification: 400X

Location on Ferrogram: Entry

Grease Sample: #3

Lubricant Base: Synthetic diester

Thickener: Silica

Solids: Silica

Solvent Type: Solvent #3

Operating History: Fresh grease

Sample Source: Manufacturer

Remarks:

Higher magnification photo of F1439 in bichromatic light shows the fine silica particles.

Photo No. F1442-13 Magnification: 100X

Location on Ferrogram: Entry

Grease Sample: #4

Lubricant Base: Silicone

Thickener: Lithium

Solids: None

Solvent Type: Solvent #3

Operating History: Fresh grease

Sample Source: Manufacturer

Remarks: Some metal particles. Most of deposit is a high concentration of soap materials used in this type of grease. The used silicone greases show an entirely different deposit and these agglomerates disappear under heat and pressure.

Photo No. F1442-14 Magnification: 400X

Location on Ferrogram: Entry

Grease Sample: #4

Lubricant Base: Silicone

Thickener: Lithium

Solids: None

Solvent Type: Solvent #3

Operating History: Fresh grease

Sample Source: Manufacturer

Remarks:

An enlarged view of Photo F1442-13 above.

Photo No. F1442-15 Magnification: 100X

Location on Ferrogram: @ 51.5 mm

Grease Sample: #4

Lubricant Base: Silicone

Thickener: Lithium

Solids: None

Solvent Type: Solvent #3

Operating History: Fresh grease

Sample Source: Manufacturer

Remarks:

Polarized light photo shows typical agglomerated particles found in this type of fresh silicone grease.

Photo No. F1442-16 Magnification: 400X

Location on Ferrogram: @ 51.5 mm

Grease Sample: #4

Lubricant Base: Silicone

Thickener: Lithium

Solids: None

Solvent Type: Solvent #3

Operating History: Fresh grease

Sample Source: Manufacturer

Remarks:

Magnified (400X) view of polarized light Photo F1442-15 circled above.
No evidence of such structures in used silicone greases. See Photos F1491-36 and F1491-37.

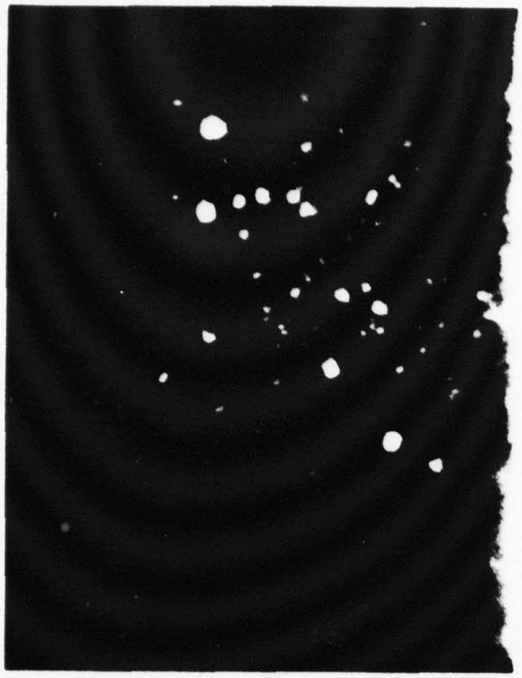

Photo No. F1442-17 Magnification: 100X

Location on Ferrogram: Entry (edge)

Grease Sample: #4

Lubricant Base: Silicone

Thickener: Lithium

Solids: None

Solvent Type: Solvent #3

Operating History: Fresh grease

Sample Source: Manufacturer

Remarks:

This sample diluted 5:1 with Solvent #3. Large soap particles much reduced in size compared to original sample shown in Photos F1442-13 to -16.

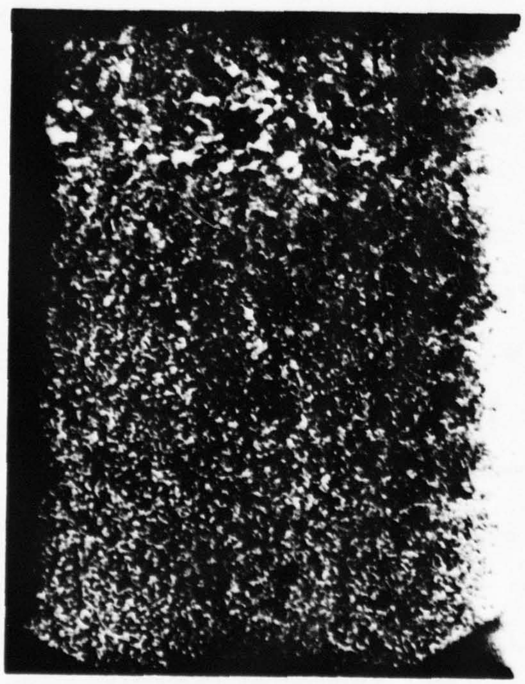

Photo No. F1442-18 Magnification: 400X

Location on Ferrogram: Entry

Grease Sample: #4

Lubricant Base: Silicone

Thickener: Lithium

Solids: None

Solvent Type: Solvent #3

Operating History: Fresh grease

Sample Source: Manufacturer

Remarks:

Enlarged view (400X) in bichromatic light of diluted (5:1) fresh silicone grease sample shows how particles are dispersed.

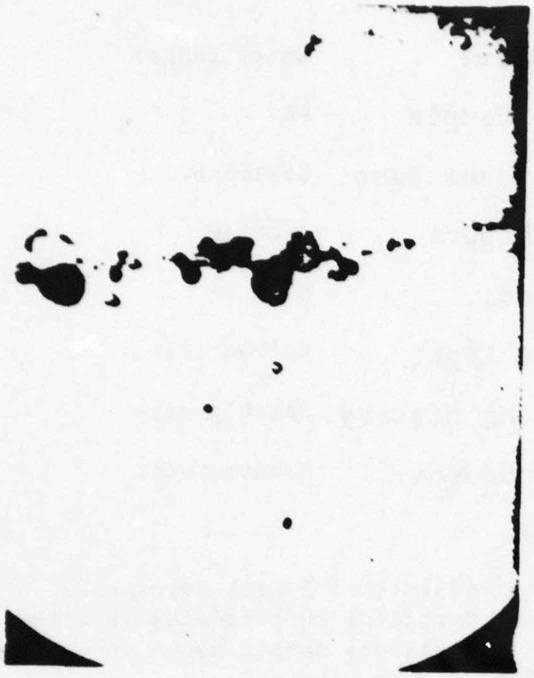

Photo No. F1434-19 Magnification: 400X

Location on Ferrogram: Entry

Grease Sample: #5

Lubricant Base: Petroleum

Thickener: Aluminum complex

Solids: None

Solvent Type: Solvent #2

Operating History: Fresh grease

Sample Source: Manufacturer

Remarks:

Sample dissolved in 10 cc of grease Solvent #2. Metallic and non-metallic debris occluded with undissolved grease. Compare to F1438-20 below dissolved with grease Solvent #3.

Photo No. F1438-20 Magnification: 400X

Location on Ferrogram: Entry

Grease Sample: #5

Lubricant Base: Petroleum

Thickener: Aluminum Complex

Solids: None

Solvent Type: Solvent #3

Operating History: Fresh grease

Sample Source: Manufacturer

Remarks:

Sample dissolved with grease Solvent #3. Except for minor amounts of metallic and non-metallic debris, substrate free of grease. Grease Solvent #3 clearly more effective than Solvents #1 and #2.

Photo No. F1440-21 Magnification: 400X

Location on Ferrogram: Entry

Grease Sample: #6

Lubricant Base: Petroleum

Thickener: Mixed metal soap

Solids: Molybdenum disulfide

Solvent Type: Solvent #3

Operating History: Fresh grease

Sample Source: Manufacturer

Remarks:

Sample dissolved in 10 cc grease Solvent #3. All MoS_2 particles settled in sample bottle or turret tube. Only minor amounts deposited on substrate.

Photo No. F1444-22 Magnification: 100X

Location on Ferrogram: Entry

Grease Sample: #6

Lubricant Base: Petroleum

Thickener: Mixed Metal Soap

Solids: Molybdenum disulfide

Solvent Type: Solvent #3/MIL-L-23699, 50/50

Operating History: Fresh grease

Sample Source: Manufacturer

Remarks:

Sample dissolved in a 50/50 mixture of Solvent #3 and MIL-L-23699 in order to suspend MoS_2 particles. Compare to Ferrogram F1440-21 above.

Photo No. F1444-23 Magnification: 400X

Location on Ferrogram: Entry

Grease Sample: #6

Lubricant Base: Petroleum

Thickener: Mixed metal soap

Solids: Molybdenum disulfide

Solvent Type: Solvent #3/MIL-L-23699 50/50

Operating History: Fresh grease

Sample Source: Manufacturer

Remarks:

Enlarged view (400X) of Photo F1444-22. Some particles exceed 50 μm. MoS_2 particles have entirely different configuration in used greases.

Photo No. Magnification:

Location on Ferrogram:

Grease Sample:

Lubricant Base:

Thickener:

Solids:

Solvent Type:

Operating History:

Sample Source:

Remarks:

Photo No. F1441-24 Magnification: 400X

Location on Ferrogram: Entry (edge)

Grease Sample: #7

Lubricant Base: Petroleum

Thickener: Clay (Bentone)

Solids: Molybdenum disulfide

Solvent Type: Solvent #3

Operating History: Fresh grease

Sample Source: Manufacturer

Remarks:

MoS_2 particles smaller in size than in grease sample #6. Entry area shows a mixture of MoS_2 and clay.

Photo No. F1441-25 Magnification: 400X

Location on Ferrogram: Entry (edge)

Grease Sample: #7

Lubricant Base: Petroleum

Thickener: Clay (Bentone)

Solids: Molybdenum disulfide

Solvent Type: Solvent #3

Operating History: Fresh grease

Sample Source: Manufacturer

Remarks:

Same as Photo F1441-24, but in bichromatic light. Differences between Bentone particles (transparent) and MoS_2 (red).

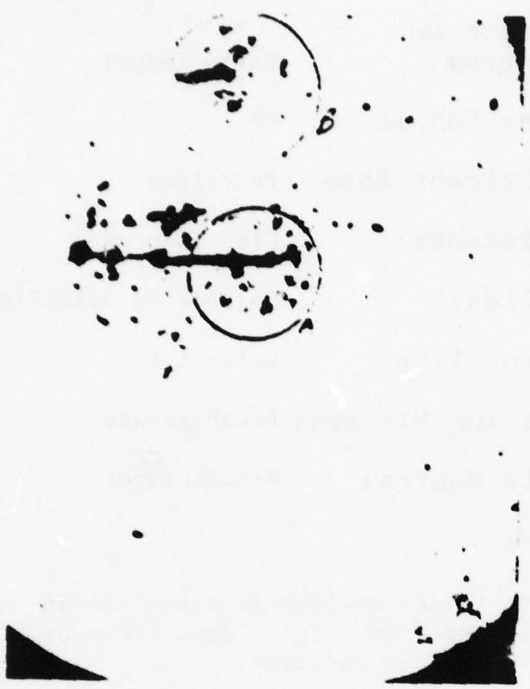

Photo No. F1443-26 **Magnification:** 100X

Location on Ferrogram: Entry

Grease Sample: #8

Lubricant Base: Petroleum

Thickener: Barium Complex

Solids: None

Solvent Type: Solvent #3

Operating History: Fresh grease

Sample Source: Manufacturer

Remarks:

Locatons A & B (circles) show metallic particles caught in web-like mass. Composition unknown.

Photo No. F1443-27 Magnification: 400X

Location on Ferrogram: @ 51.5 mm

Grease Sample: #8

Lubricant Base: Petroleum

Thickener: Barium Complex

Solids: None

Solvent Type: Solvent #3

Operating History: Fresh grease

Sample Source: Manufacturer

Remarks:

Web-like deposit away from entry area @ 51.5 mm.

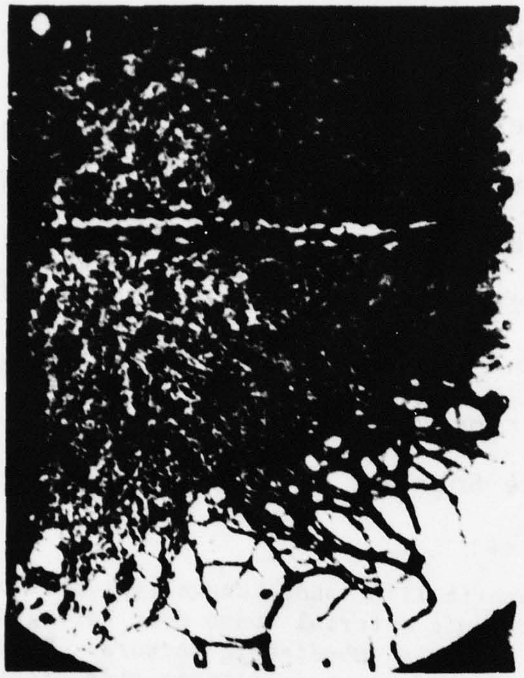

Photo No. F1443-28 Magnification: 400X

Location on Ferrogram: Re: Circle "A" on Photo No. F1443-26

Grease Sample: #8

Lubricant Base: Petroleum

Thickener: Barium Complex

Solids: None

Solvent Type: Solvent #3

Operating History: Fresh grease

Sample Source: Manufacturer

Remarks:

Large (200 μm) metal particle in large network-like mass of organic material.

Photo No. F1443-29 Magnification: 400X

Location on Ferrogram: Same as above

Grease Sample: #8

Lubricant Base: Petroleum

Thickener: Barium Complex

Solids: None

Solvent Type: Solvent #3

Operating History: Fresh grease

Sample Source: Manufacturer

Remarks:

Ferrogram F1443 heated to 625°F, 90 seconds. Organic material fuses and shrinks. Blue portion of metal (arrow) indicates low carbon steel.

Photo No. F1443-30 Magnification: 400X

Location on Ferrogram: @ 54.6 mm

Grease Sample: #8

Lubricant Base: Petroleum

Thickener: Barium Complex

Solids: None

Solvent Type: Solvent #3

Operating History: Fresh grease

Sample Source: Manufacturer

Remarks:

Bichromatic light photo shows typical web-like organic material found over Ferrogram. Metal particle imbedded in network. This is typical of contamination in this grease sample.

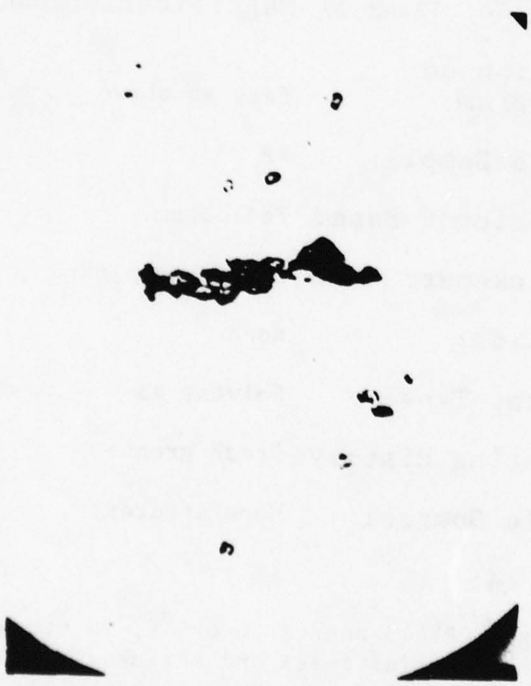

Photo No. F1443-31 Magnification: 400X

Location on Ferrogram: @ 54.6 mm (same as photo F1443-30 above)

Grease Sample: #8

Lubricant Base: Petroleum

Thickener: Barium Complex

Solids: None

Solvent Type: Solvent #3

Operating History: Fresh grease

Sample Source: Manufacturer

Remarks:

Ferrogram heated to 625°F for 90 seconds. Blue (temper color) of metal indicates low alloy steel. Web-like material evaporated by heat. Most other greases and soaps withstand this heat treatment. See next Photo (No. F1423-32), lithium type grease heated in same manner.

Photo No. F1423-32 Magnification: 100X

Location on Ferrogram: @ 54.4 mm

Grease Sample: #1

Lubricant Base: Petroleum

Thickener: Lithium

Solids: None

Solvent Type: Solvent #1

Operating History: Fresh grease

Sample Source: Manufacturer

Remarks:

The undissolved lithium type grease on the Ferrogram heated to 625°F for 90 seconds. Some smoke evolved from the heat, but otherwise remains stable.

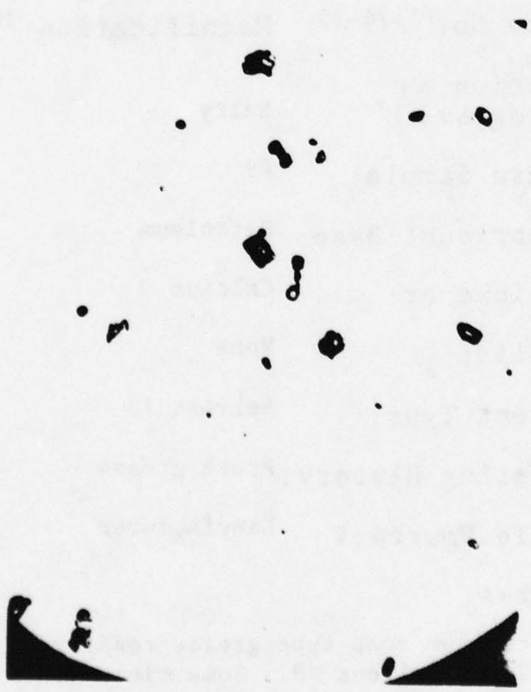

Photo No. F1479-33 Magnification: 400X

Location on Ferrogram: Entry

Grease Sample: #8

Lubricant Base: Petroleum

Thickener: Barium Complex

Solids: None

Solvent Type: Solvent #3

Operating History: Fresh grease

Sample Source: Manufacturer

Remarks:

Barium complex type grease diluted 10:1. Much of the web-like organic material is dispersed.

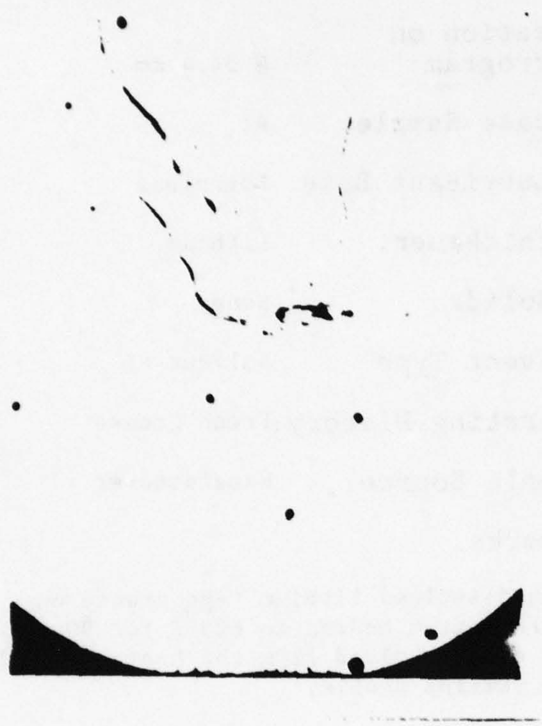

Photo No. F1479-34 Magnification: 400X

Location on Ferrogram: @ 54.7 mm

Grease Sample: #8

Lubricant Base: Petroleum

Thickener: Barium Complex

Solids: None

Solvent Type: Solvent #3

Operating History: Fresh grease

Sample Source: Manufacturer

Remarks:

Same Ferrogram as F1479-33, but below entry (diluted 10:1). Small metal particle easily observable despite web or organic material.

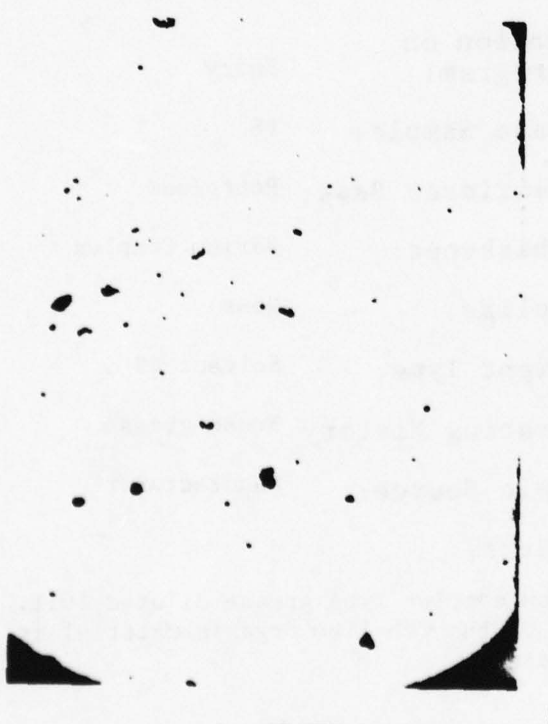

Photo No. F1474-35 Magnification: 100X

Location on Ferrogram: Entry

Grease Sample: #9

Lubricant Base: Petroleum

Thickener: Calcium

Solids: None

Solvent Type: Solvent #3

Operating History: Fresh grease

Sample Source: Manufacturer

Remarks:

This calcium soap type grease readily soluble in Solvent #3. Some minor amount of debris (dirt) in entry area.

Photo No. F1491-36 Magnification: 100X

Location on Ferrogram: Entry

Grease Sample: #4

Lubricant Base: Silicone

Thickener: Lithium

Solids: None

Solvent Type: Solvent #3

Operating History: Used grease, AISI 52-100 ball bearing & race, 80 PSI, 2 minutes

Sample Source: Manufacturer

Remarks:
Metallic wear particles easily visible in Bichromatic light. Mass of agglomerated particulate matter (see Photos No. F1442, -15 & -16) greatly reduced by wear tester action.

Photo No. F1491-37 Magnification: 400X

Location on Ferrogram: Entry

Grease Sample: #4

Lubricant Base: Silicone

Thickener: Lithium

Solids: None

Solvent Type: Solvent #3

Operating History: Used grease, same as above.

Sample Source: Manufacturer

Remarks:
Enlarged view (400X) of entry deposit in Bichromatic light. Demonstrates that large amount of soap material in used silicone grease present low interference when observing metal particles microscopically.

Photo No. F1491-38 Magnification: 400X

Location on Ferrogram: Entry area

Grease Sample: #4

Lubricant Base: Silicone

Thickener: Lithium

Solids: None

Solvent Type: Solvent #3

Operating History: Used grease same as F1491-38.

Sample Source: Manufacturer

Remarks:

Another view in Bichromatic light showing contrast between metallic wear particles and non-metallic debris.

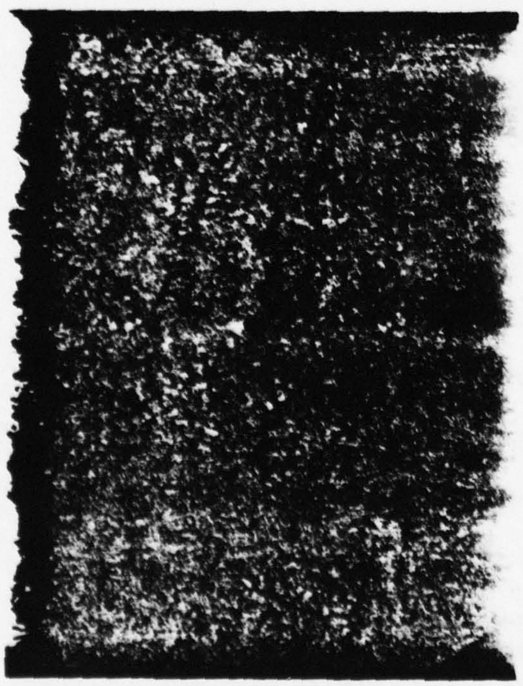

Photo No. F1491-39 Magnification: 400X

Location on Ferrogram: 54.5 mm

Grease Sample: #4

Lubricant Base: Silicone

Thickener: Lithium

Solids: None

Solvent Type: Solvent #3

Operating History: Used grease same as F1497-38.

Sample Source: Manufacturer

Remarks:

View of typical metallic wear particles down from entry area. These particles readily identifiable from non-metallic debris in background using Bichromatic light.

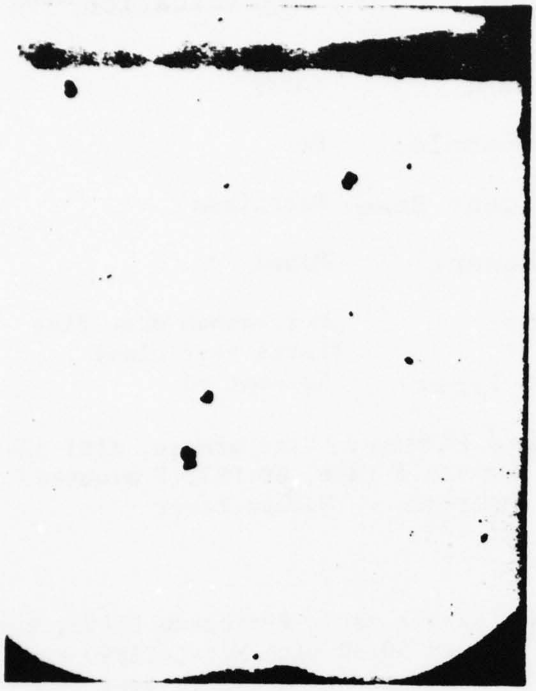

Photo No. F1493-40 Magnification: 100X

Location on Ferrogram: Entry

Grease Sample: #6

Lubricant Base: Petroleum

Thickener: Mixed

Solids: Molybdenum disulfide (large particle size)

Solvent Type: Solvent #3

Operating History: Used grease, AISI 52-100 ball & race, 80 PSI, 2 minutes.

Sample Source: Manufacturer

Remarks:

Lack of any significant deposit of metal caused by rapid settling in sample bottle. Typical of MoS_2 greases.

Photo No. F1493-41 Magnification: 400X

Location on Ferrogram: Entry

Grease Sample: #6

Lubricant Base: Petroleum

Thickener: Mixed

Solids: Molybdenum disulfide

Solvent Type: Solvent #3

Operating History: Used grease, same as above.

Sample Source: Manufacturer

Remarks:

Isolated worn MoS_2 particle. Compare this and Photo above to Photos F1494-42 where MIL-L-23699 oil was used to suspend particles in solvent solution.

Photo No. F1494-42 Magnification: 400X

Location on Ferrogram: Entry

Grease Sample: #6

Lubricant Base: Petroleum

Thickener: Mixed

Solids: Molybdenum disulfide (large particles)

Solvent Type: Solvent #3

Operating History: Used grease, AISI 52-100 ball bearing & race, 80 PSI, 2 minutes.

Sample Source: Manufacturer

Remarks:

Same grease sample as in Ferrogram F1493, but Solvent #3 mixed 50/50 with MIL-L-23699 to suspend wear particles. Metallic wear particles readily observed on substrate.

Photo No. F1494-43 Magnification: 400X

Location on Ferrogram: Entry

Grease Sample: #6

Lubricant Base: Petroleum

Thickener: Mixed

Solids: Molybdenum disulfide

Solvent Type: Solvent #3/ MIL-L-23699 50/50

Operating History: Used grease, as above.

Sample Source: Manufacturer

Remarks:

View of metallic wear particles in Bichromatic light.

Photo No. F1492-44 Magnification: 100X

Location on Ferrogram: Entry

Grease Sample: #8

Lubricant Base: Petroleum

Thickener: Barium complex

Solids: None

Solvent Type: Solvent #3

Operating History: Used grease, AISI 52-100 ball bearing against race, 80 PSI, 2 min.

Sample Source: Manufacturer

Remarks:

General view of entry deposit in Bichromatic light. Very little interference from web-like deposit found in fresh barium greases in viewing metallic wear particles.

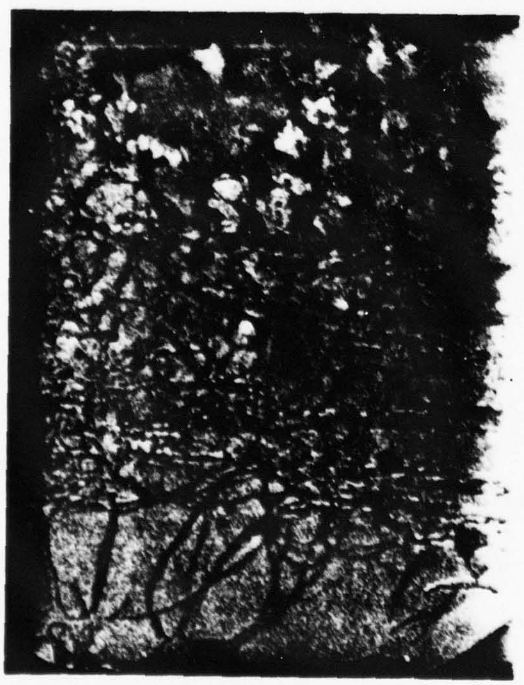

Photo No. F1492-45 Magnification: 400X

Location on Ferrogram: Entry (edge)

Grease Sample: #8

Lubricant Base: Petroleum

Thickener: Barium complex

Solids: None

Solvent Type: Solvent #3

Operating History: Used grease, as above.

Sample Source: Manufacturer

Remarks:

Enlarged (400X) Bichromatic light view of metallic wear particles against background of web-like organic material. See also heated Ferrogram (Photo No. F1492-46).

Photo No. F1492-46 Magnification: 400X

Location on Ferrogram: Entry

Grease Sample: #8

Lubricant Base: Petroleum

Thickener: Barium complex

Solids: None

Solvent Type: Solvent #3

Operating History: Used grease

Sample Source: manufacturer

Remarks:

Ferrogram F1492 heated to 625°F for 90 seconds. Just as with fresh greases, organic network disappeared on heating, leaving metallic particles with typical blue oxide temper colors.

Photo No. Magnification:

Location on Ferrogram:

Grease Sample:

Lubricant Base:

Thickener:

Solids:

Solvent Type:

Operating History:

Sample Source:

Remarks:

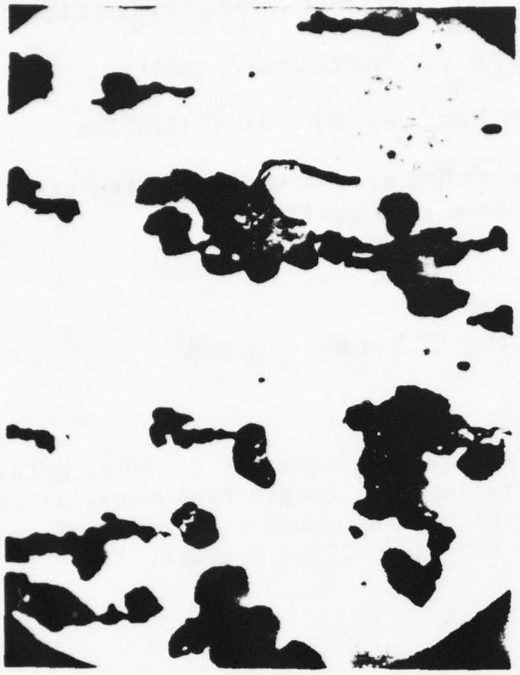

Photo No: F1940-1 Magnification: 400x

Location on Ferrogram: entry

Grease Sample: #1 - no dilution

Sample Source: Landing gear nosewheel of E-2 Grumman two tapered roller bearings residual grease.

Operating History: X

Remarks:

All debris, including metallic particles, probably contamination of original grease translucent material is residual soap.

Photo No: F1943-1 Magnification: 400x

Location on Ferrogram: entry

Grease Sample: #2 - no dilution

Sample Source:
Same bearing as above. Grease removed from race.

Operating History: x

Remarks:

Low wear metal concentration. The primary difference to the above reference sample is the presence of oxides and compounds that may be wear associated or contaminants. Bearing appears normal

Photo No: F1964-1 Magnification: 400x

Location on Ferrogram: entry

Grease Sample: #3 10:1 dilution

Sample Source: F-4 wheel - outer race - sample from race surface.

Operating History: x

Remarks:

Clean Ferrogram in terms of residual grease and contaminants. Larger free metal particles (> 10 μm) give appearance of repeated passage through rolling contact.

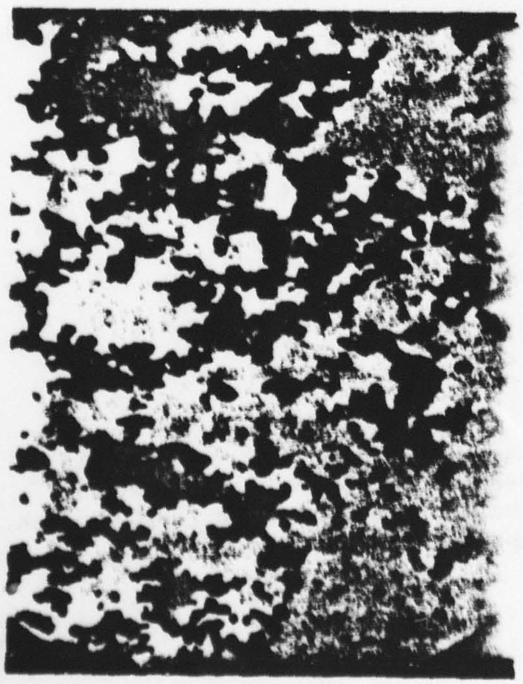

Photo No: F1965-1 Magnification: 400x

Location on Ferrogram: entry

Grease Sample: #4 100:1 dilution

Sample Source: Swash plate H53 helicopter. Grease from outside of seal, possibly residue of fitting grease.

Operating History:

Hours on unit: 1203 - Since overhaul: 353

Remarks:

Heavily contaminated.

Photo No: F1946-1 Magnification: 400x

Location on Ferrogram: entry

Grease Sample: #5 no dilution

Sample Source: Swash plate, H53 Helicopter. Grease from behind spacer, probably has not come in contact with rolling elements.

Operating History: hours on unit - 1203.
since overhaul - 353

Remarks:

Considering the sample source, there are present a surprisingly large number of severe wear particles.

Photo No: F1966-1 Magnification: 400x

Location on Ferrogram: entry

Grease Sample: #6 100:1 dilution

Sample Source: Swash plate, H53 Helicopter. Grease from upper bearing around ball. Probably some from bearing edge.

Operating History: hours on unit - 1203
since overhaul - 353

Remarks:

Heavy deposits of friction polymer.

Photo No: F1967-1 Magnification: 400x

Location on Ferrogram: entry

Grease Sample: #7 10:1 dilution

Sample Source: Swash plate, H53 helicopter. From upper bearing around ball. Opposite side from Sample #6.

Operating History: hours on unit - 1203
since overhaul - 353

Remarks:

Photo No: F1968-1 Magnification: 400x

Location on Ferrogram: entry

Grease Sample: #8 10:1 dilution

Sample Source: Swash plate H53 helicopter. From the bearing edge (inside edge).

Operating History: hours on unit - 1203
since overhaul - 353

Remarks:

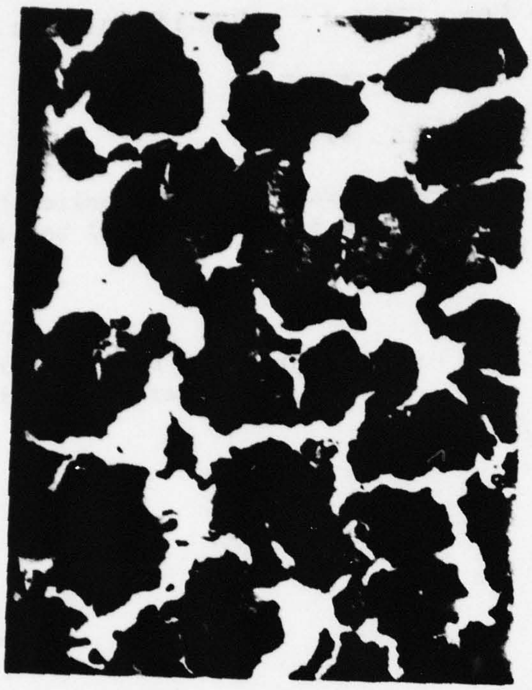

Photo No: F1969-1 Magnification: 400x

Location on Ferrogram: entry

Grease Sample: #9 10:1 dilution

Sample Source: Swash plate H53 helicopter. Same as #7. Upper bearing around ball. Attempted to clear edge grease sway.

Operating History: hours on unit - 1203
since overhaul - 353

Remarks:

Photo No: F1970-1 Magnification: 400x

Location on Ferrogram: entry

Grease Sample: #10 10:1 dilution

Sample Source: Swash plate H53 helicopter. Lower bearing inside edge.

Operating History: hours on unit - 1203
since overhaul - 353

Remarks:

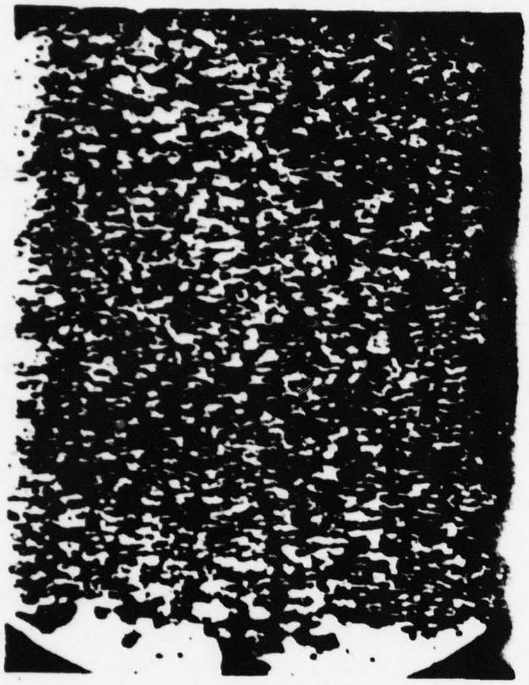

Photo No: F1975-1 Magnification: 400x

Location on Ferrogram: entry

Grease Sample: #11

Sample Source: Swash plate H53 helicopter. Sample removed from between two ball bearings (lower).

Operating History: hours on unit - 1203
since overhaul - 353

Remarks:

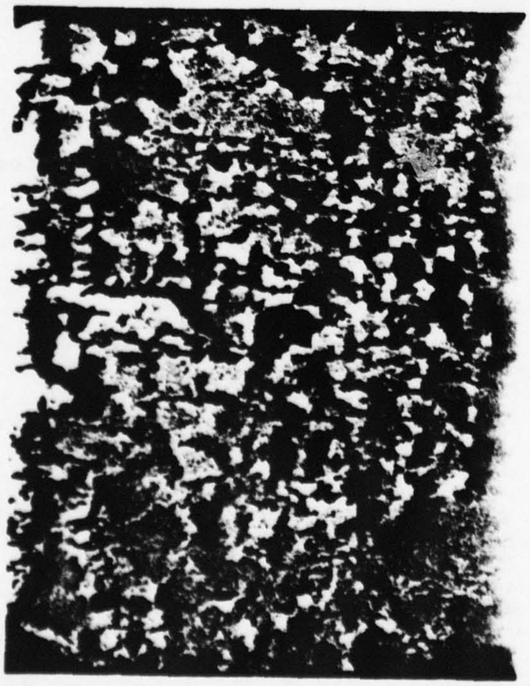

Photo No: F1977-1 Magnification: 400x

Location on Ferrogram: entry

Grease Sample: #12 100:1 dilution

Sample Source:
Taken from same area as Sample #11 above.

Operating History: same as above

Remarks:

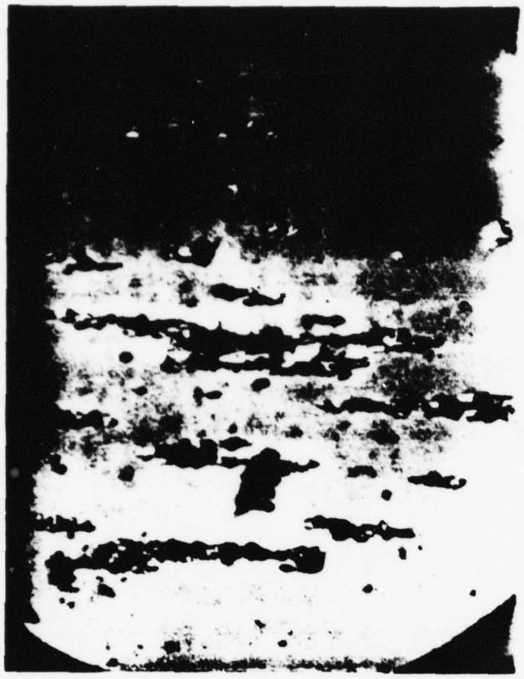

Photo No: F1978-1 Magnification: 400x

Location on Ferrogram: entry

Grease Sample: #13 100:1 dilution

Sample Source: Helicopter.
Reduction gear for rotor folding.
Sampled at crack in gear box housing.

Operating History: hours on unit - 1203
since overhaul - 353

Remarks:

Photo No: F1979-1 Magnification: 400x

Location on Ferrogram: entry

Grease Sample: #14 100:1 dilution

Sample Source: Helicopter
Reduction gear.
Sampled at gear teeth (minor gear)

Operating History: hours on unit - 1203
since overhaul - 353

Remarks:

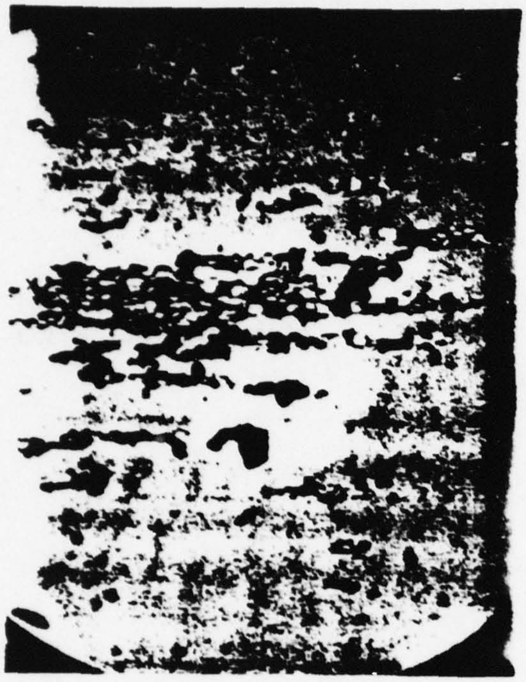

Photo No: F1980-1 Magnification: 400x

Location on Ferrogram: entry

Grease Sample: #15 100:1 dilution

Sample Source: Helicopter.
Reduction Gear. Sampled at gear teeth.
Similar to sample #13, but not at crack.

Operating History: hours on unit - 1203
since overhaul - 353

Remarks:

Photo No: F1957-1 Magnification: 400x

Location on Ferrogram: entry

Grease Sample: #16 not diluted

Sample Source: Helicopter.
Reduction Gear. Sample taken from
sliding bearing.

Operating History:

Remarks:
Heavy free metal deposits.

Photo No: F1958-1 Magnification: 400x

Location on Ferrogram: entry

Grease Sample: #17 not diluted

Sample Source: Helicopter Reduction Gear. Sampled from planetary gear teeth.

Operating History: hours on unit - 1203
since overhaul - 353

Remarks:

Photo No: F1986-1 Magnification: 1000x

Location on Ferrogram: edge of entry

Grease Sample: #17 10:1 dilution

Sample Source:

same as above

Operating History: same as above

Remarks:

Photo No: F1987-1 Magnification: 400x

Location on Ferrogram: entry

Grease Sample: #18 10:1 dilution

Sample Source: Helicopter Reduction Gear. Sampled from gear support region.

Operating History: hours on unit - 1203
since overhaul - 353

Remarks:

Photo No: F1959-1 Magnification: 400x

Location on Ferrogram: entry

Grease Sample: #18 no dilution

Sample Source: same as above

Operating History: same as above

Remarks:

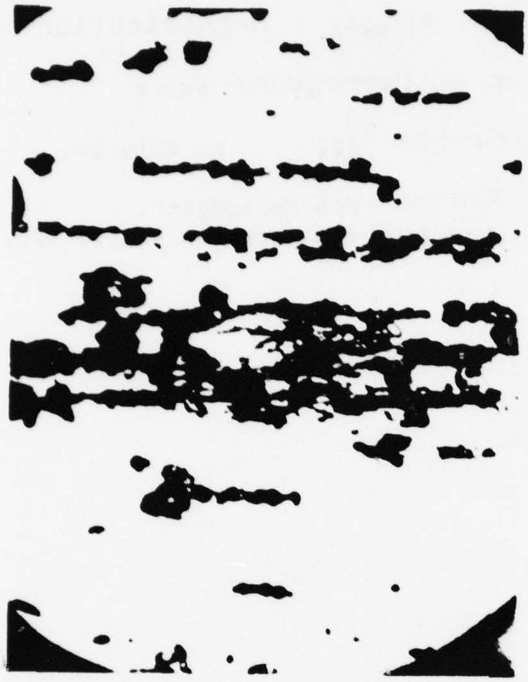

Photo No: F1960-1 Magnification: 400x

Location on Ferrogram: entry

Grease Sample: #19 no dilution

Sample Source: H46 Helicopter.
Stationary splines at rotor head.
Sample taken below bottom spline.

Operating History: not applicable

Remarks:

Photo No: F1961-1 Magnification: 400x

Location on Ferrogram: entry

Grease Sample: #20 no dilution

Sample Source: H46 Helicopter.
Stationary splines at rotor head.
Sample taken off spline surfaces.

Operating History: not applicable

Remarks:

Photo No: F1962-1 Magnification: 400x

Location on Ferrogram: entry

Grease Sample: #21 no dilution

Sample Source: H46 helicopter.
Sample taken from same area as sample #20.

Operating History: not applicable

Remarks:

Photo No: Magnification:

Location on Ferrogram:

Grease Sample:

Sample Source:

Operating History:

Remarks:

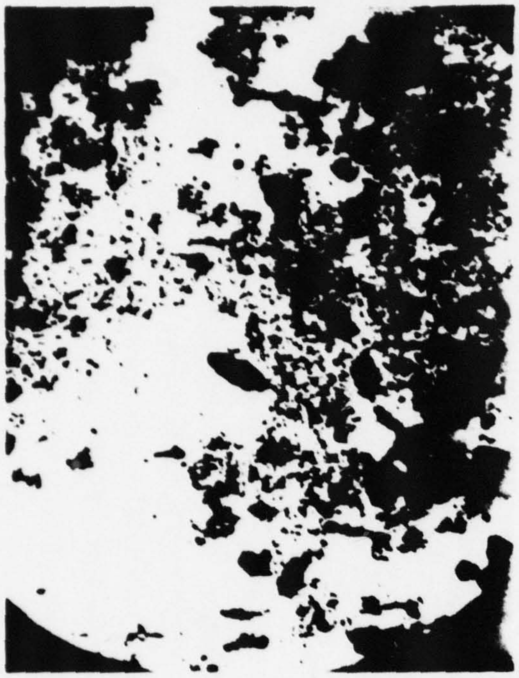

Photo No: F1990-1 Magnification: 400x

Location on Ferrogram: entry

Grease Sample: #22 100:1 dilution

Sample Source: CH 53A aircraft.
Tail rotor spline, sampled directly from spline, open to environment in parked position.

Operating History: not applicable

Remarks:

Photo No: F1991-1 Magnification: 400x

Location on Ferrogram: entry

Grease Sample: #23 100:1 dilution

Sample Source: CH 53A aircraft.
Sample taken from same location as sample #22. Appeared very dirty.

Operating History: not applicable

Remarks:

DISTRIBUTION LIST

FMC CORP.
727 23rd St. South
Box 2708
Arlington, VA 22202
Attn: A. Adams

Advanced Technology, Inc.
7926 Jones Branch Dr.
McLean, VA 22101
Attn: Michael R. Adelman

NCR Corp.
B-30 Rm. 305
Dayton, OH 45469
Attn: C. H. Aneshansley

Foxboro Nederland, N.V.
Netherlands Sales Office
S-Gravelandseweg 557
P.O. Box 1113, Schiedam
Attn: Arie den Boer

Aeronautical Research Labs.
506 Lorimer Street
Fishermen's Bend
Box 4331 PO Melbourne
Victoria 3001
Australia
Attn: M. Atkin

U.S. Army Mobility Equipment
R&D Center
Attn: STSFB-HM
Ft. Belvoir, VA 22060

U.S. Army Air Mobility
R&D Lab
Attn: SAVDL-EV-MOR
Ft. Eustis, VA 23604

Machine Design
Attn: Bob Aronson
Penton Plaza
Cleveland, OH 44114

Army Air Mob. R&D Lab
Attn: Everett Bailey, Lewis Dir.
NASA Lewis
Cleveland, OH 44101

Hobart Corp.
Attn: Gary E. Banks
711 W.H.Q. Ave.
Troy, OH 45374

Union Carbide Corp.
Nuclear Div.
P.O. Box 1410
Paducah, KY 42001
Attn: Betty Barbre

Southwest Research Institute
8500 Culebra Rd.
P.O. Drawer 28510
San Antonio, TX 78284
Attn: John R. Barton

Tyrone Hydraulics Inc.
Attn: Dean Basham
P.O. Box 511
Corinth, MS 38834

Donald A. Becker
Manager, Reclaimed Oil Program
Physics B-50
National Bureau of Standards
Washington, DC 20234

Oklahoma State University
Fluid Power Research Center
Stillwater, OK 74077
Attn: Leonard Bensch

IIT Research Institute
Attn: Mr. S. Bhattacharyya
10 W. 35th Street
Chicago, IL 60616

Aircraft Porous Media, Inc.
Attn: F. E. Bishop
A Subsidiary of Pall Corp.
30 Sea Cliff Ave.
Glen Cove, NY 11542

Morgan Construction Co.
Attn: John A. Bjork
15 Belmont St.
Worcester, MA 01601

DISTRIBUTION LIST - Continued

Delco Products Div.
GMC
Dayton, OH 45401
Attn: Harold D. Corwin

Dr. H. Courten
Grumman Aerospace Corp.
Bethpage, NY 11714

J. Coyle
Villanova University
Villanova, PA 19085

L. Cramer
Bureau of Engraving & Printing
14th & C Sts., S.W.
Washington, DC 20226

Dr. J. D. Crisp
University of Dayton
Mechanical Engineering
300 College Park
Dayton, OH 45469

S. B. Crowe
The Aerospace Corp.
Library Acquisitions (ADR)
P.O. Box 92957
Los Angeles, CA 90009

J. P. Cuellar
Southwest Research Institute
8500 Culebra Road
P.O. Box 28510
San Antonio, TX 78284

Prof. H. Czichos
Bundesanstalt Furmaterialprufung
Under Den Eichen 87
1 Berlin 45
W. Germany

M. D'Agnostino
Grumman Aerospace Corp.
Bethpage, NY 11714

Dr. H. Dalal
SKF Industries, Inc.
1100 1st Avenue
King of Prussia, PA 19406

V. Davidson
HIAC Division
Pacific Scientific
4719 W. Brooks
Montclaire, CA 91763

Mr. Davis
Commander
Naval Ship Engr. Ctr. (6101F)
Prince George Center
Center Bldg.
Hyattsville, MD 20782

J. F. Dill, Dr.
AF Aero Propulsion Lab
AFAPL/SFL
Wright-Patterson Air Force Base
OH 45433

Dr. R. A. Ditaranto
Prof. of Engineering
PMC Colleges
School of Engineering
Chester, PA 19013

E. Ditto
Manufacturing Dev.
General Motors Tech. Center
Warren, MI 48090

G. Donovan (AIR-417)
Naval Air Systems Command
Dept. of Navy
Washington, DC 20361

A. J. D'Orazio
NAPTC
Trenton, NJ 08628

Dr. D. Dowson
Univ. of Leeds
Leeds LSZ 9Jt
UK

Naval Air Systems Command Rep. PAC
George E. Dulong, Code 102
Naval Air Station North Island
San Diego, CA 92135

DISTRIBUTION LIST - Continued

Prof. H. Blok
Univ. of Tech Delft
2 Mekelweg
Delft, Holland

Eastern Airlines
Miami Int'l Airport
Miami, FL 33148
(E.P. Blyskal)

Conklin Company, Inc.
Valley Park Drive
Shakopee, MN 55379
Attn: Russell Bockstedt

Dr. W. Bolton
SKF Ltd
Luton
Bedfordshire LU31JF
UK

Mr. Charles Bowen
Transmission Consultants, Inc.
360 Place Office Park
P.O. Box 748
Arlington, TX 76010

Dr. Roderick E. Bowen
Foxboro Analytical
P.O. Box 435
78 Blanchard Road
Burlington, MA 01803

BOWLES (SY-42)
Naval Air Station
Patuxent River, MD 20670

Naval Ship Engineering Center
Philadelphia, PA 19111
Attn: Stanley Brittingham

Ms. Broetzman
Schroeder Brothers
Pitts. Area/Wash. Area
8425 Hilltop Road
Fairfax, VA 22030

Arinc Research Corp.
2551 Riva Road
Annapolis, MD 21401
Attn: H. Brown

Stuart H. Brown
Chevron Research Co.
576 Standard Ave.
Richmond, CA 94802

Don Buckley
NASA Lewis Research Center
Cleveland, OH 44114

Prof. R. Burton
Dept. of M.E.
Northwestern University
Evanston, IL 60201

Mr. L. Butcher
Mod. Quality Assurance
Directorate
Whitehall, London
UK

Colby Buzzell
General Electric
50 Fordham Road
Wilmington, MA 01887

A. Caliendo
Commander
AF Logistics COM (MMEA)
Wright-Patterson Air Force Base
Dayton, OH 45433

P. Camberg
Naval Aviation Logistics Center Pacific
Code 102
Naval Air Station North Island
San Diego, CA 92135

Mr. A. Cameron
Prof. of Lubrication
Imperial College of Science
& Technology
London, England

Dr. E. Capone
Universita di Napoli
80125 Napoli
Italia
08-16-14-165

DISTRIBUTION LIST - Continued

D. Carson
Pall Corp.
30 Sea Cliff Ave.
Glen Cove, L.I., NY 11542

Mr. P. Centers
AF Aero Propulsion Lab/SFL
Wright Patterson Air Force
Base, OH 45433

Dr. Chevalier
Dept. of the Army
Project Mgr.
USAMC
DRCPM-IAP-T
P.O. Box 209
St. Louis, MO 63166

Naval Aviation Integrated Logistic
Support Center
Patuxent River, MD 20670
Attn: C. Chandler

M. Chiogioji
Commander
Naval Ordance Systems Com.
(ORD-0442)
Navy Dept.
Washington, DC 20360

J. Ciccarello
Grumman Aerospace Corp.
Advanced Systems
Plant 05
Bethpage, L.I., NY 11714

P. Clack
Leeds & Northrup
Dept. MD 337
North Wales, PA 19454

R. A. Collacott
Leicester Polytechnic
Fault Diagnosis Center
P. O. Box 143
Leicester CE1 9BH UK

Mr. Collegeman
Commander Naval Air Systems Command
(AIR-53645A)
Navy Dept.
Washington, DC 20361

W. E. Coman
Bendix
211 Seward Ave.
Utica, NY 13503

Commander
Letterkenny Army Depot
Chambersburg, PA 17201
Attn: MAIDS Bldg. 37

Commander
Naval Air Force, U.S. Pacific
Code 5313
Owaho, Hawaii 96860

Commander
Naval Ordnance Station
Code 5044
Louisville, KY 40214

Commander
Naval Sea Systems Command
Code 04321H
Washington, DC 20362

Commanding Officer
Naval Air Rework Facility
Code 360
Naval Air Station
Pensacola, FL 32508

A. Conte
Naval Air Development
Center, Code 30212
Warminster, PA 18974

Dr. N. H. Cook
Massachusetts Institute of Technology
77 Massachusetts Avenue
Cambridge, MA 02139

A. S. Coolidge, Design Engineer
United Aircraft Prods., Inc.
Box 1035
Dayton, OH 45401

Ms. J. Copsey
Fisher & Paykel Ltd
Mt. Wellington Hwy.
Auckland, New Zealand

DISTRIBUTION LIST - Continued

Delco Products Div.
GMC
Dayton, OH 45401
Attn: Harold D. Corwin

Dr. H. Courten
Grumman Aerospace Corp.
Bethpage, NY 11714

J. Coyle
Villanova University
Villanova, PA 19085

L. Cramer
Bureau of Engraving & Printing
14th & C Sts., S.W.
Washington, DC 20226

Dr. J. D. Crisp
University of Dayton
Mechanical Engineering
300 College Park
Dayton, OH 45469

S. B. Crowe
The Aerospace Corp.
Library Acquisitions (ADR)
P.O. Box 92957
Los Angeles, CA 90009

J. P. Cuellar
Southwest Research Institute
8500 Culebra Road
P.O. Box 28510
San Antonio, TX 78284

Prof. H. Czichos
Bundesanstalt Furmaterialprufung
Under Den Eichen 87
1 Berlin 45
W. Germany

M. D'Agnostino
Grumman Aerospace Corp.
Bethpage, NY 11714

Dr. H. Dalal
SKF Industries, Inc.
1100 1st Avenue
King of Prussia, PA 19406

V. Davidson
HIAC Division
Pacific Scientific
4719 W. Brooks
Montclaire, CA 91763

Mr. Davis
Commander
Naval Ship Engr. Ctr. (6101F)
Prince George Center
Center Bldg.
Hyattsville, MD 20782

J. F. Dill, Dr.
AF Aero Propulsion Lab
AFAPL/SFL
Wright-Patterson Air Force Base
OH 45433

Dr. R. A. Ditaranto
Prof. of Engineering
PMC Colleges
School of Engineering
Chester, PA 19013

E. Ditto
Manufacturing Dev.
General Motors Tech. Center
Warren, MI 48090

G. Donovan (AIR-417)
Naval Air Systems Command
Dept. of Navy
Washington, DC 20361

A. J. D'Orazio
NAPTC
Trenton, NJ 08628

Dr. D. Dowson
Univ. of Leeds
Leeds LSZ 9Jt
UK

Naval Air Systems Command Rep. PAC
George E. Dulong, Code 102
Naval Air Station North Island
San Diego, CA 92135

DISTRIBUTION LIST - Continued

Q.E.D. Systems, Inc.
370 Kings Center
2350 Virginia Beach Blvd.
Virginia Beach, VA 23452
Attn: P. Dulong

Cdr. E. Dunsford
Mod Ships Maint. Authority
Portsmouth PO6 4AA
UK

Dr. B. Edinoff
Chief Chemical Engineer
Rockwell International
Automotive Operation
2135 W. Maple
Troy, MI 48084

Dr. K. Eisentraut
Aerospace Research Lab
ARL/LJ
Wright-Patterson AFB
Dayton, OH 45433

G. A. Ekstrom
Eaton Corp.
11000 Roosevelt Blvd.
Philadelphia, PA 19115

David H. Elazar
Israel Aircraft Industries Ltd
Technical Information Center
Ben-Gurion International Airport
Israel

Daniel Fairchild
Chief Technical Officer
FRAM Corp.
105 Pawtucket Avenue
East Providence, R.I. 02916

Gene Falendysz
J. I. Case
700 State Street
Racine, WI 53404

Mr. H. H. Farmer
Mgr-Petroleum Res & Dev
R. T. Vanderbilt Co., Inc.
30 Winfield Street
East Norwalk, CT 06855

L. Fassi
Fiat-S.A.-Stabilimento Rivalta
Carrozzeria
Program Manager
Via 1-MAGGIS, 99
10090 Rivalta Di Torino, Italy

R. Wakelin
Univ. of Leeds
Leed LS2-9JT
UK

L. L. Fehrenbacher
AFML/MBT
Wright-Patterson AFB, OH 45433

Richard S. Fein
Texaco, Inc.
Beacon Research Labs
P. O. Box 509
Beacon, NY 12508

Seymour Feiurstein
Aerospace Corp.
Interfacial Science Rept.
A6-2647
P.O. Box 92957
Los Angeles, CA 98009

George D. Ferlic
United States Steel Corp.
1807 E. 28th St.
Lorraine, OH 44055

Dr. J. Fodor
Research Institute of Automotive Ind.
1016 Budapest 1.
Naphegy Ter 5/b
Hungary

Carmine J. Forzono
USAF-Wright-Patterson AFB
Aeronautical Systems Div.
Wright-Patterson AFB, OH 45433

Mr. J. Frasca
U.S. Information Agency
25 "M" Street SW
Washington, DC 20547

70

DISTRIBUTION LIST - Continued

J. Frontiero
NAVAIRSYSCOM
AIR 4114
Washington, DC 20361

Ms. Major Britt Gabel
Naval Air Development
Center, Code 30212
Warminster, PA 18974

P. Gadd
Naval Aircraft Materials Lab
Royal Naval ACFT Yard
Fleetlands
Gosport, Hants
UK

G. Gainer
Servodyne, Inc.
2120 Marrietta Blvd.
Atlanta, GA 30318

Mr. George Saama
MMEW-14
Kelley AFB, TX 78241

Paul George
Pratt & Whitney Aircraft Co.
400 Main Street
East Hartford, CT 06108

Lt. Col. A. Giusti
Aeronautica Militare Direzione
Laboratori
Via Tuscolana 473
00181 Roma, Italia

Nathan Glassman
David W. Taylor
Naval Ship R&D Center
Annapolis, MD 21402

J. Glidden
HYDRECO
9000 E. Michigan Ave.
Kalamazoo, MI 49003

Prof. M. Godet
Institut Nat'l Des Sciences Appliquees
20 Ave. Albert Einstein
69621 Villeurbanne, France

Rich Gold
Commanding Officer
Naval Ordnance Station
Indian Head, MD 20649
Attn: Code 5231R

Dr. I. L. Goldblatt
Exxon Research & Engineering Co.
P.O. Box 51
Linden, NJ 07036

Dr. G. Golden
United Technologies Research Center
East Hartford, CT 06108

Toni Goldoftas
Hydraulics & Pneumatics Magazine
614 Superior Ave. West
Cleveland, OH 44113

A. Goldsmith
Thermal Control Co. Ltd.
138 Old Shoreham Rd.
Hove, Sussex BN3 7BW
UK

William T. Greene
Clark Equipment Co.
Corporate Laboratories
324 East Dewey Ave.
Buchanan, MI 49107

Duane Grimm
Sunstrand Aviation
4747 Harrison Ave.
Rockford, IL 61101

Edward Griswold
The Oil Polishing Co.
340 W. 26th St. - Suite P
National City, CA 92050

DISTRIBUTION LIST - Continued

Dr. Guttenburger
Materialprufstalle der Bundeswehr
Lanshuter Strasse 70
D8058 Erding
West Germany

Major Haberbusch
ASD/RAOC
Wright-Patterson AFB, OH 45433

F. Hall
AIR 3406
NAVAL AIR SYSTEMS COM
Washington, DC 20361

Dr. L. G. Hampson
National Center of Tribology
Risley Nuclear Power Development Labs
UKAEA
Risley, Warrington WA3 GAT UK

F. Handshaw CW3
Commanding Officer
507th Transportation Co. (GS)
Ft. Campbell, KY 42223
Attn: ASOAP Lab

D. Haney
Drott Manufacturing
P.O. Box 1087
Wausau, WI 54401

R. Hanson
Technical Center Bldg. G.
Catipillar Tractor Co.
Peoria, IL 61629

Commander R. Healy (MAT-0413)
Chief of Naval Material
Navy Department
Washington, DC 20360

Dr. W. Hecker
Staatliches Forschungsinstitut
FIIR Geochemir
86 Bamberg
Concordrastrafze 28 BRD

Henry R. Hegner
Man Tech
Century Bldg., Suite 930
2341 Jefferson Davis Hwy.
Arlington, VA 22202

David B. Hester
General Electric
Mail Stop M82
Cincinnati, OH 45215

Jim Hirvonen
Code 6673
HRL
Washington, DC 20375

William H. Hite
National Machinery Co.
Tiffin, OH 44883

M. Hoobchack
Naval Sea Systems CMD
Code 04321H
Washington, DC 20362

Mr. R. Hoffman
Commander, U.S. Army Aviation
Sys. Command
P. O. Box 209
St. Louis, MO 63166
Attn: AMSAV-LSA

Martin Jackson
Lubrication Engineers, Inc.
5945 Myers Road
Ft. Worth, TX 76111

J. Jamieson
Defense Research & Dev. Staff
British Defense Staff
British Embassy
Washington, DC 20008

Russell Janke
International Harvester
7 S. 600 County Line Rd.
Hinsdale, IL 60521

DISTRIBUTION LIST - Continued

N. L. Jarvis
Naval Research Lab
Washington, DC 20375

E. Jewell
Naval Air Development Center
Code 30212
Warminster, PA 18974

Dr. John Joseph
Tech. Program Mgr.
Gulf Oil Corp.
Gulf Radiation Tech.
P. O. Box 608
San Diego, CA 92112

Dr. Johnson
Michigan Technical University
College of Engineering
Houghton, MI 49931

J. Johnson
Fluid Power Society
432 E. Kilbourn Ave.
Milwaukee, WI 53202

Walter Johnson
Materials Research
Deere & Company
Maline, IL 61265

Greffin Jones
JOAP TSL
Naval Air Station
Pensacola, FL 32508

Howard F. Jones
AFAPL/SFL
Wright Patterson AFB, OH 45323

M. Jones
Univ. of Swansea
Singleton Park
Swansea SA 2 8PP UK

W. Jones
Abex Corp.
1160 Dublin Road
Columbus, OH 43216

Hans Jurstrand
Sales Engineer
FFV. Maintenance Div
Aircraft
CVA S-73200 ARBOGA, Sweden

John M. Karhnak
U.S. Dept. of the Interior
Bureau of Mines
Division of Mining Research
2401 "E" Street, N.W.
Washington, DC 20241

Pete Karpovich
NAPTC
Trenton, NJ 08608

R. Kight
Commanding Officer, Code 347
NARF, Naval Air Station
Pensacola, FL 32508

Shep Kinsman
Coulter Electronics Inc.
590 W. 20th Street
Hialeah, FL 33010

Erwin Kirnbauer
Pall Corp.
Glen Cove, L.I., NY 11542

Col. R. Kliemann
Reg. Mgr.
E/M Lubricants, Inc.
129 Eisenhower Lane So.
Lombard, IL 60148

G. Kling
Caterpillar
100 N.E. Adams
Peoria, NY

J. Knife
TRW Globe
2275 Stanley Avenue
Dayton, OH 45404

H. Koba
Massachusetts Institute of Technology
77 Massachusetts Ave.
Cambridge, MA 02139

DISTRIBUTION LIST - Continued

G. Kokotailo
Mobil R&D Corp.
Paulsboro, NJ 08066

Dr. Ralph Korlow
Korlow Scientific Co.
7800 River Road
N. Bergen, NJ 07047

T. Koster
Commercial Shearing Inc.
1775 Logan Avenue
Youngstown, OH 44501

A. Kraft
NAVAIR AIR 53431
Washington, DC 20361

Steve Lada
NAVAIRSYSCOM AIR 55232D
Washington, DC 20361

E. R. Lamson
Naval Air Development Center
Code 3021
Warminster, PA 18974

Dr. J. Lancaster
RAE Farnborough
Farnborough
Hants GU14 6TD
UK

Donald Larson
Caterpillar Tractor
Joliet, IL 60434

Dr. W. Lauder
Univ. of Strathclyde
James Weir Bldg.
75 Montrose St.
Glasgow GI 1XJ
Scotland, UK

R. P. Layne
Commander
Naval Ship Engr. Center (6101F)
Prince George Center
Center Bldg.
Hyattsville, MD 20782

Lear Siegler, Inc.
74 Inuerness Drive East
Englewood, CO 80110

Joint Oil Analysis Program
Code 360
Naval Air Rework Facilities
Pensacola, FL 32508

Philip G. Leigh
Director, Environment Sci.
Systron Donner Corp.
One Systron Drive
Concord, CA 94520

A. J. Lemanski
Boeing Vertol Inc.
Mail Drop P32-09
P. O. Box 16858
Philadelphia, PA 19142

Dr. Lawrence Leonard
The Franklin Institute Research Lab
20th & Benjamin Franklin Parkway
Philadelphia, PA 19103

S. J. Leonardi
Mobil R&D Corp.
Paulsboro, NJ 08066

Energy & Water Research Laboratory
US Army Mobility Equipment
Research & Development Command
Fort Belvoir, VA 22060
Attn: M. Lepera

Gordon D. LeQuire
Systems Engineering Test Directorate
Naval Air Test Center
Patuxent River, MD 20670

Alvin Lieberman
Royco Instruments, Inc.
141 Jefferson Drive
Menlo Park, CA 94025

Robert O. Link
Program Manager
The Oil Polishing Co.
340 W. 26th St. - Suite P
National City, CA 92050

DISTRIBUTION LIST - Continued

O. Lloyd
Marchwood Eng. Lab
Marchwood, Southampton SO4-42B
UK

D. Lubrano
US Army Air Mobility R&D Lab
Eustis Directorate
Ft. Eustis, VA 23604

J. B. Luciw
Baird-Atomic
125 Middlesex Tpk
Bedford, MA 01730

Malte Lukas
Baird-Atomic
125 Middlesex Tpk
Bedford, MA 01730

T. Lyle
Commander
Naval Air Systems Command (AIR-5523)
Navy Department
Washington, DC 20361

Kendall McBroom
Donaldson Co., Inc.
1400 W. 94th Street
Minneapolis, MN 55431

George McCain
OC-ALC/MMETTM
Tinker AFB, OK 73145

A. T. McClelland
Commander
Naval Ships Systems Command
(SHIPS -045N)
Navy Department
Washington, DC 20360

John McCoy
Carborundum Co.
Commercial Filters Div.
Lebanon, IN 46052

P. McCullagh
National Engineering Laboratory
East Kilbride
Glasgow G150QU
Scotland, UK

Mr. John McGrew Jr.
Shaker Research Corp.
Northway 10 Executive Park
Ballston Lake, NY 12019

Dr. P. MacPherson
Imperial College of Science & Tech.
Prince Consort RD
London SW7 2BX UK

P. J. Mangione
NAPTC
Trenton, NJ 08628

Dr. Manieri
Instituto Per Le Richerchi Di
Technologia Meccania
10080 Vico Canaverse
Torino, Italia

Peter Mardora
Dayton T. Brown, Inc.
Church Street
Bohemia, L.I., NY 11716

Milt Margolis
RCA Service Co.
5260 Port Royal Road
Springfield, VA 22151

M. D. Martin
Chief of Naval Material (MAT-03425)
Navy Department
Washington, DC 20360

LCDR. H. Martin
Office of Naval Research, Code 221
Arlington, VA 22217

R. A. Masom
Smiths Industries Ltd
Winchester Rd
Basingstoke, Hants RGZZ 6HP
UK

Tom Maxwell
General Electric
I75 & Junior Road
Evendale, OH 45215

DISTRIBUTION LIST - Continued

John D. Meakin
Manager
Physics of Materials Lab
The Franklin Institute Res. Labs
20th & Parkway
Philadelphia, PA 19103

C. Merhib
Army Material & Mechanics Research
Watertown, MA 02172

L. Messerole
Commanding Officer
Naval Air Rework Facility (Code 345)
Bldg. 341
Naval Air Station, North Island
San Diego, CA 92135

Dr. J. Meyer
Ford Motor Company Research Lab
Dearborn, MI 48120

D. Metcaff
Commander
Naval Ship Engr. Center (6107C)
Prince George Center
Center Bldg.
Hyattsville, MD 20782

Michel Michael
John Deere Waterloo Tractor Works
P. O. Box 270
Waterloo, IA 50704

John Middleton
Trans-Sonics, Inc.
P.O. Box 326
Lexington, MA 02173

Lt. R. Miller
Office of Naval Research 441-6
Rm 631, Ballston Towers #1
800 N. Quincy St.
Arlington, VA 22217

J. Miner
Pratt & Whitney Aircraft Div.
Engineering Dept.
United Aircraft Corp.
East Hartford, CT 06108

D. Minuti
Naval Air Development Center
Code 606
Warminster, PA 18974

M. Mistry
Hall Thermotank Int. Ltd.
Home Gardens
Dartford, Kent UK

Bruce Mitchell
Allied Chemical Corp.
Hopewell Chemical Plant
P.O. Box 761
Hopewell, VA 23860

Dr. Wm. Moddeman
University of Dayton
Research Institute
Dayton, OH 45469

Mr. B. Moffat
35TFW/FMS-MAFMF/NDI
SOAP Lab.
George AFB, CA 92392

Dr. Moore
Chief of Naval Material (MAT 033)
Navy Department
Washington, DC 20360

Robert Moran
Mectron Ind. Inc.
9857 Remer Street
South El Monte, CA 91733

Robert Mott
Mechanical Engr. Tech.
University of Dayton
Dayton, OH 45469

Dr. Mueller
Commander
Naval Air Systems Command (AIR-310C)
Navy Department
Washington, DC 20361

Miss Carol E. Mulvaney
Caterpillar Tractor Co.
Technical Information Center
Technical Center
Peoria, IL 61629

DISTRIBUTION LIST - Continued

Mat Musallam
USAREUR Material Lab
APO NY 09028

James L. Newcombe
Hatco Chemical Div.
W.R. Grace & Co.
King George Post Rd.
Fords, NJ 08863

J. R. Nicholas
NAVSEC Code 610
Washington, DC 20360

Nicholas Gerald
Naval Ordnance Station
Louisville, KY 40214

Louis Niebergall
Deluxe Products Corp.
1201 Michigan Blvd.
Racine, WI 53402

Ron Nilson
NAVSEC Code 6107
Washington, DC 20360

Jack C. Norman
Lubrication Engineers
P.O. Box 6178
Toledo, OH 43614

Dr. J. Oberteuffer
Sala Magnetics Inc.
247 Third St.
Cambridge, MA 02142

J. F. Ohlson
Naval Air Development Center
Code 3021
Warminster, PA 18974

M. S. Ovalvo
National Science Foundation
Eng. Mech. Div.
1800 G Street
Washington, DC

Victor J. Orphan, Manager
Nuclear Tech Br.
Gulf Oil Corp.
Gulf Radiation Tech.
P.O. Box 608
San Diego, CA 92112

Dr. S. Osborn
Franklin Institute Research Lab
20th and Parkway
Philadelphia, PA 19103

L. Packer
United Technologies
Research Center
East Hartford, CT 06108

Pall Corporation
Glen Cove, L.I., NY 11542
Attn: C. P. Tsai

Dr. E. Passeglia
National Bureau of Standards
Metallurgy Division
Institute For Materials Research
Washington, DC 20234

G. Pate
Yard Ltd
Charing Cross Tower
Glasgow G2 4PP
Scotland, UK

Dr. J. Patten
Battelle
Battelle Blvd.
Richland, WA 99353

William T. Patterson
Warner Gear Div.
Borg Warner Corp.
1106 E. Seymour
Muncie, IN 47302

Daniel E. Pauze
USAAMRDL EUSTIS DIRECTORATE
SAVDL-EU-TAP
Ft. Eustis, VA 23604

DISTRIBUTION LIST - Continued

James E. Peake
Bradford
National Corporation
Street 70
Two Research Place
Rockville, MD 20850

C. Pearson
Delaval-Stork V.O.F.
P. O. Box 329
7550 AH Hengelo (OV.)
Netherlands

Technical Center
Catipillar Tractor Co.
Peoria, IL 61629
Attn: Dr. Perez

Dr. S. Pergament
Ocean Environmental Systems Ltd.
16 Sutton Road
Monsey, NY 10952

J. Perry
Danfoss
DK6430 Nordberg
Denmark

H. Peterson
MRA&L
Pentagon Room 2B322
Washington, DC

M. Peterson
Wear Sciences, Inc.
32 Sutherland Dr.
Scotia, NY 12302

Dr. Jay D. Pinson, Director
Grad. School of Engineering
University of Dayton
Dayton, OH 45469

G. Pocock
Admiralty Materials Lab
Holton Heath Poole
Dorset BH16 6JU

Daniel Popgosheu
NAPTC
Trenton, NJ 08628

Bernard L. Poppert
Naval Air Systems Command (AIR-340E)
Washington, DC 20361

B. Poteate
Commander
US Army Air Mobility R&D Lab
Eustis Directorate (SAVDL-EU-MOA)
Ft. Eustis, VA 23604

R. Powell
Arinc Res. Corp.
2551 Riva Rd.
Annapolis, MD 21401

Mr. C. A. Preskitt
Intelcom Rad Tech
7650 Convoy Ct.
P.O. Box 80817
San Diego, CA 92138

S. Raddiffe
CE9B
Berkeley Nuclear Lab
Berkeley, Gloucestershire UK

R. L. Rainwater
Ford Tractor Operations
Industrial Equip. Engineering
2500 East Maple
Troy, MI 48084

Mr. A. Rasberry
Corpus Christi Army Depot
Corpus Christi, TX 78419
Attn: AMXAD-ZLS

Hal Ravner
Code 6170
Naval Research Laboratory
Washington, DC 20375

B. Reason
Cranfield Inst. of Tech.
Cranfield, Bedford MK43 OAL
UK

N. D. Rebuck
Naval Air Development Center
Code 30212
Warminster, PA 18974

DISTRIBUTION LIST - Continued

Commander D. Reed
Chief of Naval Material (MAT-03425)
Navy Department
Washington, DC 20360

J. Remsen
Chief of Naval Material (MAT-033)
Navy Department
Washington, DC 20360

G. F. Rester
NAVSEC
6107C1
N.S.E.C.
Washington, DC 20362

Dr. E. Van Reuth
ARPA
1400 Wilson Blvd.
Arlington, VA 22209

B. Richter
Commander
AF Logistics Com. (MMEA)
Wright-Patterson AFB
Dayton, OH 45433

E. J. Robbins
National Centre of Tribology
Risley Engr. & Materials Lab
U.K.A.E.A. Risley
Warrington Lancs

F. Robinson
Rolls Royce
P. O. Box 3
Filton BS12 7QE
UK

H. Robmann
Motoren un Turbinen Union
Dachauer Strabe 665
Postfach 50 0640
D8000 Munchen 50
West Germany

Mel Rosen
G.E. Aircraft Eng. Group
1000 Western Ave. - Bldg. 2-40
Lynn, MA 01901

Commander
Naval Ships System Command
(SHIPS 03421)
Navy Department
Washington, DC 20360
Attn: Rosenbaum

Dr. Rosenwasser
Commander
Naval Air Systems Command (AIR-310C)
Navy Department
Washington, DC 20361

E. Rounds
Commander
Naval Air Systems Command (AIR-41732C)
Navy Department
Washington, DC 20361

B. Roylance
University College of Swansea
Dept. of Mech. Engineering
Singleton Park
Swansea SAZ 8PP UK

Dr. William Ruff
National Bureau of Standards
Metallurgy Division
Institute for Materials Research
Washington, DC 20234

John Rumbarger
The Franklin Institute Research Lab
20th & Benjamin Franklin Parkway
Philadelphia, PA 19103

A. W. Russell
HIAC Division
Pacific Scientific
4719 W. Brooks
Montclaire, CA 91763

Ms. Jeannette Sanders
Oil Analysis Laboratory
Naval Air Station, North Island
San Diego, CA 92135

Dom Sangillo
Velcon Filters, Inc.
1750 Rogers Avenue
San Jose, CA 95112

DISTRIBUTION LIST - Continued

V.R.K. Sastry
Dept. of Mechanical Engineering
University College of Swansea
Singleton Park, Swansea
SA2 8PP UK

Mr. A. F. Scelza
Research Tool and Die Co.
Route 73
Maple Shade, NJ 08052

Robert Schaefer
Millipore Corp.
Bedford, MA 01730

F. W. Schaekel
Mobility Equipment
R&D Command
Ft. Belvoir, VA 22060

Richard D. Schieman
Standard Oil Co. of Ohio
3092 Broadway
Avon Lake, OH 44012

J. Schlichtig
Grumman Aerospace Corp.
Bethpage, NY 11714

Daniel A. Schock
Minster Machine Co.
240 W. 5th Street
Minster, OH 45865

Commander Schoenthal
Danish Naval Material Command
Holmen
DK1433 Copenhagen
Denmark

Harold A. Schuetz
Army AVSCOM
P.O. Box 209
St. Louis, MO 63166
Attn: DRSAV-EQP

Herbert W. Scibbe
NASA - Lewis Research Center
Cleveland, OH 44135

Mr. D. Scott
Paisley College of Tech.
High Street
Paisley PA1 2BE UK

A. Seitz
Nelson Filter
P.O. Box 280
Stoughton, WI 53589

John Shimski
NAPTC
Trenton, NJ 08628

Hiroshi Shiomi
Electro Technical Laboratory
Tanashi Branch
5-4-1 Mukodai-Machi, Tanaski-SHI
Tokyo, Japan

Mr. J. Shorlock
Pure Carbon Co.
St. Mary's, PA 15857

Norm Shute
Analysts, Inc.
700 Silver Spur Road
Rolling Hills Estates, CA 90274

L. Sibley
SKF Industries Inc.
1100 First Avenue
King of Prussia, PA 19406

R. G. Sieber
Sunstrand Service Corp.
4751 Harrison Avenue
Rockford, IL 61101

Robert S. Silva
The Foxboro Co.
Foxboro, MA 02035

G. Skala
Environment One
2773C Ball Town Road
Schenectady, NY 12309

DISTRIBUTION LIST - Continued

G. Smith
Commander
Naval Air Systems Command (AIR-53441)
Navy Department
Washington, DC 20361

Dr. Howard Smith
Professor & Chairman
Mechanical Engineering
University of Dayton
Dayton, OH 45469

N. Smith
Commander
III Corps
Fort Hood, TX 76541
Attn: AF2F-BMNT-AL, Bldg. 7012

Ralph B. Snapp
David W. Taylor Naval Ship
R&D Center
Annapolis, MD 21402

Leon Stallings
Naval Air Development Center
Code 30212
Warminster, PA 18974

John Stark
The Irving-Cloud Publishing Co.
7300 North Cicero Avenue
Lincolnwood, Chicago, IL 60646

R. Steele
Dept. of Transportation
Transportation System Center
Kendall Square
Cambridge, MA 02142

G. Stewart
Naval Safety Center (121)
Naval Air Station
Norfolk, VA 23511

John Stone, Manager
Control System Lab.
The Franklin Institute Research Lab.
20th & Parkway
Philadelphia, PA 19103

Jack Stover
Timken Company
1835 Dveburg Avenue SW
Canton, OH 44706

Dr. N. Suh
Lab. for Manu. & Productivity
School of Engineering
Mass. Institute of Technology
Cambridge, MA 02139

Eli Symlaglou
Millipore Corp.
Bedford, MA 01730

Kiyoshi Takeuchi
Kyodo Yushi Co. Ltd
Tokyo, Japan

Thomas Tauber
Technical Development Co.
24 E. Glenolden Avenue
Glenolden, PA 19036

David W. Taylor
Naval Ship R&D Center
Annapolis, MD 21402

Dr. R. Tessman
Oklahoma State University
Fluid Power Research Center
Stillwater, OK 74074

G. R. Thompson
Owens Corning Fiberglass
Newark, OH 43055

Bernard Tober
Naval Air Systems Command (AIR-536)
Washington, DC 20361

R. Tremain
Nobrac Carbon Ltd
Marlborough Road
Lancing, Sussex UK

A. G. Troiani
SKF Industries Inc.
1100 First Avenue
King of Prussia, PA 19406

DISTRIBUTION LIST - Continued

G. Tsuchida
Commander
Naval Ordnance Systems Command
(ORD-0442F)
Navy Department
Washington, DC 20360

R. Valori
Commanding Officer
Naval Air Propulsion Test Center
Trenton, NJ 08628
Attn: Code PE-72RV

M. L. Valtierra
Southwest Research Institute
8500 Culebra Road
P.O. Drawer 28510
San Antonio, TX 78284

Prof. O. Vingsbo
Uppsala University
Box 534
S751 Z1 Uppsala
Sweden

C. Waggoner
Defense Research Establishment
Pacific
FMO VOS 1BO Victoria
British Columbia, Canada

J. Ward
Commander
Naval Air System Command (AIR-4115C)
Navy Department
Washington, DC 20361

J. Watson
Commander
Naval Weapons Systems Analysis Office
(WSAO-20) Washington Navy Yard
Bldg. 210
Washington, DC 20374

Philip Wernberg
Naval Air Systems Command (AIR-52032E)
Washington, DC 20361

E. P. Wennert
Commander
Naval Ship Engineering Center
Philadelphia Division
Philadelphia, PA 19112
Attn: Code 6734

Vernon Wescott
Foxboro Analytical
P.O. Box 435
78 Blanchard Road
Burlington, MA 01803

R. Widner
Timken Inc.
1835 Duber Avenue S.W.
Canton, OH 44706

D. Williams
Pall Europe Ltd
Walton Road
Portsmouth PO6 1TD UK

J. E. Willin
The Motor Industry Research Assoc.
Watling Street, Nuneaton
Warwickshire, CV10 OTU UK

Mr. H. Winters
58FMS/SOAP Lab.
Luke AFB, AZ 85309

V. Wittenbreder
Commander
U.S. Army Maintenance Mgmt. Center
Lexington/Bluegrass Army Depot
(AMXMD-TP)
Lexington, KY 40507

Milton G. Wittig
Lubrication Engineers Inc.
3851 Airport Freeway
Ft. Worth, TX 76111

R. Duncan-White
Royco Insr. Inc.
700 Willow Lane
W. Dundee, IL 60118

DISTRIBUTION LIST - Continued

Robert Wolff
Mech. Engr. Tech.
University of Dayton
Dayton, OH 45469

E. Wright
Commanding Officer
Naval Air Development Center
AVTD (CODE 30224)
Warminster, PA 18974

Mrs. Rebecca Wright
AF Aero-Propulsion Lab
AFAPL/SLF
WPAFB, OH 45433

Russel W. Wright
Trans-Sonics Inc.
Burlington, MA 01803

Kang Yi
U.S. Dept of Labor - OSHA
216 N. Waco
Wichita, KS 67202

Dr. G. Youdan
Perkins Engines Co.
Peter Borough, PE1-5NA UK

R. W. Young
Continental Oil
Fuels & Lubricants
Pomca City, OK 74601

Dr. M. Zlotnik
Department of Energy
Washington, DC 20545

Dr. John Zuk
NASA
Lewis Research Center
Cleveland, OH 44101

DISTRIBUTION LIST

NAVAIRENGCEN
1115
9011 (2)
92A1B
92A12 (2)
92724 (20)

DDC (12)
NAVAIRSYSCOM
AIR-954 (2)

*** DISTRIBUTION CONTINUED ON PAGES 67 THROUGH 84 ***

REVISION LIST

REVISION	PAGES AFFECTED	DATE OF REVISION